Innovation of motion axes for laser machine

Master Thesis

TECHNICAL UNIVERSITY OF LIBEREC
Faculty of Mechanical Engineering ∎

Master Thesis Assignment Form

Innovation of motion axes for laser machine

Name and surname: **Ram Kumar Ramesh**
Identification number: S19000365
Study programme: N2301 Mechanical Engineering
Study branch: Machines and Equipment Design
Assigning department: Department of Manufacturing Systems and Automation
Academic year: **2020/2021**

Rules for Elaboration:

1. Introduction to the construction of a laser machine in KSA laboratories.
2. Basic control calculations of motion axes with currently used components.
3. Propose changes for possible increase of feed rates and acceleration of individual axes.
4. Design of a different drive unit for axis movement than the one currently in use.

Scope of Graphic Work:
Scope of Report: 60 pages
Thesis Form: printed/electronic
Thesis Language: English

List of Specialised Literature:

[1] BUDYNAS, R. G. and J. K. NISBETT. Shigleys Mechanical Engineering Design (in SI Units). 10th ed. Asia: McGraw-Hill, 2015, 1104 p. ISBN 978-981-4595-28-5.
[2] MAREK, J. et al. Design of CNC Machine Tools. Praha: MM publishing, 2015, 730 p. ISBN 978-80-260-8637-6.
[3] HIWIN, online catalogues, https://www.hiwin.com/index.html

Thesis Supervisors: Ing. Petr Zelený, Ph.D.
                          Department of Manufacturing Systems and Automation

Date of Thesis Assignment: November 19, 2020
Date of Thesis Submission: May 19, 2022

L.S.

prof. Dr. Ing. Petr Lenfeld   Ing. Petr Zelený, Ph.D.
              Dean   Head of Department

Liberec   March 5, 2020

Declaration

I hereby certify, I, myself, have written my master thesis as an original and primary work using the literature listed below and consulting it with my thesis supervisor and my thesis counsellor.

I acknowledge that my bachelor master thesis is fully governed by Act No. 121/2000 Coll., the Copyright Act, in particular Article 60 – School Work.

I acknowledge that the Technical University of Liberec does not infringe my copyrights by using my master thesis for internal purposes of the Technical University of Liberec.

I am aware of my obligation to inform the Technical University of Liberec on having used or granted license to use the results of my master thesis; in such a case the Technical University of Liberec may require reimbursement of the costs incurred for creating the result up to their actual amount.

At the same time, I honestly declare that the text of the printed version of my master thesis is identical with the text of the electronic version uploaded into the IS/STAG.

I acknowledge that the Technical University of Liberec will make my master thesis public in accordance with paragraph 47b of Act No. 111/1998 Coll., on Higher Education Institutions and on Amendment to Other Acts (the Higher Education Act), as amended.

I am aware of the consequences which may under the Higher Education Act result from a breach of this declaration.

May 28, 2021   Ram Kumar Ramesh

ACKNOWLEDGEMENT

It is with immense gratitude; I acknowledge the support of my university for providing me this great opportunity to develop in deepest manner my engineering skills while accomplishing this diploma thesis and help them to further develop the importance in machine construction design.

I would like to thank, **Ing. Petr Zeleny Ph.D.,** the supervisor and **Ing. Martin Lachman Ph.D.,** the consultant of this diploma thesis, for his helpful approach, commitment to measure, professional advice, and critical reminders.

I would also like to thank our head of the department, **Ing. Petr Zeleny Ph.D.,** again who has been a great support in every way to pursue our academics. Without his help, I might otherwise have never encountered successfully.

Furthermore, would like to thanks, **Ing. Petr Keller, Ph.D.** for providing guidance for the thesis writing.

I would also like to express my gratitude to The Department of Manufacturing Systems and Automation at the Technical university of Liberec for providing me the support I required, which gave me the opportunity to proceed freely with this work.

Finally, I am grateful to thank my whole family and friends for all the support, patience and encouragement throughout my studies.

THEME: INNOVATION OF MOTION AXES OF A LASER MACHINE

ABSTRACT: The main aim of the thesis is to enhance the motion axes of a laser machine which is available in the KSA laboratory. The major problem to overcome is to improve the feed rate of existing laser machine and cut down vibration problem. To overcome this, a detailed study of drive mechanisms which can used on laser cutting machines and an overview of different laser machines in the market has been thoroughly studied. From this research, two possible variants were considered, one of which is about enhancing the existing drive type (ball screw) by working on the parameters which will help us achieve the required feed rate and the other one is the change of whole drive type (linear motor). Finally, an optimum solution out of the two drive types has been chosen after thorough analysis of these drive types.

KEYWORDS: Laser, Laser Cutting machine, linear drives, ball screw drive type, Linear motor drive type, Feed rate, acceleration, diameter, pitch.

ABSTRAKT: Hlavním cílem práce je úprava pohybových os laserového stroje dostupného v laboratoři KSA. Hlavním úkolem je zvýšit rychlost posuvu stávajícího laserového stroje a odstranit problém s vibracemi. V prvé řadě byla provedena důkladná a podrobná studie pohonných mechanismů, které lze použít na laserových řezacích strojích, a vyhotoven přehled různých laserových strojů na trhu. Na základě tohoto průzkumu byly vytvořeny dvě možné varianty, z nichž jedna je zlepšení stávajícího typu pohonu (kuličkového šroubu) úpravou parametrů, které nám pomohou dosáhnout požadovaného posuvu, a druhou je změna celého typu pohonu (lineární motor). V závěru bylo po důkladné analýze těchto typů pohonů zvoleno optimální řešení pomocí dvou typů pohonů.

KLÍČOVÁ SLOVA: Laser, laserový řezací stroj, lineární pohony, pohon s kuličkovým šroubem, pohon s lineárním motorem, rychlost posuvu, zrychlení, průměr, stoupání.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF SYMBOLS AND ABBREVIATIONS USED

AC - Alternative Current

B (mm) - width

CAM - Computer Aided Manufacturing

CNC - Computer Numerical Control

D (mm) - Diameter

D_n (mm) - Nominal diameter

DC - Direct Current

F_x (m/min) - Feed rate

K - Support bearing factor

K_d - End fixity co-efficient

L (mm) - Length

L_{cr} (mm) - Screw length

NC - Numeric Control

N_c (rpm) - Critical speed

N_x (min^{-1}) - Speed

P (mm) – Pitch

PLC - Programmable Logic Controller

Rpm – Revolution per minutes

τ (MPa) - Shear stress

T (Nm) - Torque

TUL - Technical University of Liberec

1. INTRODUCTION

Cutting and similar processes are the most common methods of handling sheet metal for separating materials (cutting, trimming, etc.). In the past, they used presses with cutting tools for creation of holes or variously shaped semi-finished or finished product of sheet metal material. But such tools are single purpose tools and each tool must be manufactured according to required shapes and dimensions. So, this technology therefore only pays off for serial and mass manufacturing, from an economic point of view.

Since the technology which has been used did not really pay off and was not really economical, the scientists decided to apply laser in the process of producing outputs. The laser is a splendid universal unit. It has penetrated from laboratories to numerous fields of science since 160, when the first laser was developed. Its use has been used in industry, medicine and cosmetics and arts. At virtually every move, it is one of the most valuable instruments which accompanies us. Lasers are used in medicine, in surgeries and numerous surgical procedures. Lasers are used to build thermocouples in electrical engineering. Lasers are used in manufacturing for sheet, tube and profile cutting, for engraving, forging, hardening, grinding, machining and more.

2. OBJECTIVES OF THE WORK:

The main objective of this thesis work is to enhance the laser cutting machine which is available at the KSA laboratory. The laser cutting machine has been in existence for more than 10 years now and no noticeable changes till far. The main reason for to innovate the laser cutting machine is because to increase the speed of the feed rate, to cut-off the vibration and to improve the productivity. Also, to replace it with contemporary technologies.

The theoretical portion of the project will discuss several commercially available machines of similar sizes and purposes (modeling milling machines, laser cutting machines) that may be utilized for inspiration or comparison with the machine created here. They will then apply their knowledge to the creation of a machine similar to the one described in the introduction. It is also necessary to compare the linear actuators which can be applied on laser machines and finding out the best of it. Ball screw linear actuator is used in the existing laser cutting machine. It is also necessary to work on the design changes on the linear actuator when the feed rate is increased or the linear actuator assembly has to be completely changed. Finally, compare different variants to find out the optimal one.

3. LASER AND LASER CUTTING MACHINE

The word "laser" was originally an English abbreviation for Light Amplification by Stimulated Emission of Radiation, translated as "amplification of light by stimulated (forced) emission. It uses the phenomenon of stimulated emission of electromagnetic radiation active particles excited by an external energy source to produce monochromatic and coherent radiation (i.e., with one-direction oscillations, wavelengths, and phases). It is important to achieve population inversion (nonequilibrium distribution) of energy levels active atmosphere for laser beam generation.[1]

An activated medium, an optical resonator, and an excitation energy field make up the laser. Lasers are classified as gas, solid state, semiconductor, liquid, or chemical depending on the type of active environment. An optical resonator is made up of two or three mirrors, at least one of which is semipermeable. A discharge lamp, an electric discharge in an activated medium, a stream of electrons, or even a chemical reaction may all be seen as energy sources. Lasers are classified into two types: constant and pulse, depending on the type of operation.
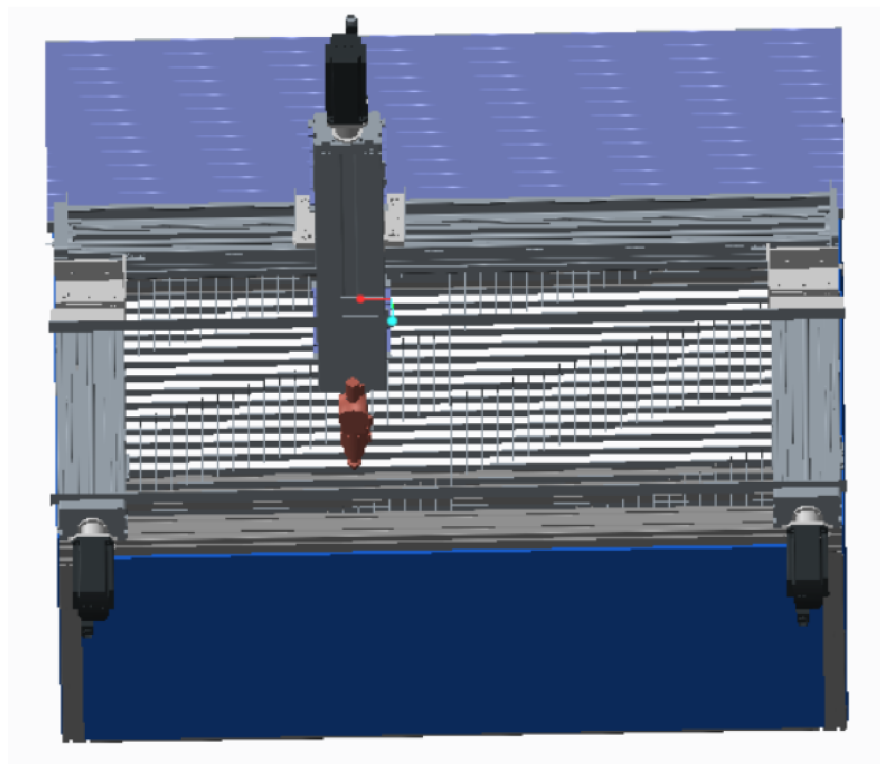
Figure 1: Design of Laser machine

In combination with numerical control, the invention of the laser used for commercial use gave rise to sheet metal processing (CNC) developments are taking on an entirely new dimension. Laser cutting machines allow cut an arbitrarily complex shape into the sheet with good accuracy, speed and cut quality. By flipping the NC software into the control system, the form created can be modified easily, enabling the use of these machines even for the development of part and small series or the construction of practical prototypes. Unlike presses, when running laser cutting machines, no major forces are produced, so these machines are not so demanding on the construction. Classified as the unconventional methods of material separation, laser cutting technology is very common in manufacturing industries today. Since then, their use has started to grow, primarily due to their positive characteristics. They open up new possibilities thanks to their efficiency and expense. Due to high precision without heating and reduced material loss, the design increasingly relies on the advantages of laser-cut tubes and profiles.

Figure 2: Current state of the machine

Using a high-powered laser beam that is operated by CNC software that defines cutting parameters, a laser cutting system can cut a range of materials. Laser cutting is extremely reliable and offers consumers a pristine cut, making it a common choice in metal fabrication shops.

The first section of the Master thesis focuses on describing the existing condition of the laser machine at the Technical University of Liberec laboratory in Building L and also explaining other basic fundamentals involved in the selection of ball screw. The main aim of my work here is to enhance the acceleration of each drive and to come up with an advanced line drive system in the existing laser machine. Also, to determine the complexity and advantages it is going to bring while doing the improvement. Also, I worked on other improvements in the laser cutting machine which improves the productivity and reduces the cost.

The laser device was for this machine designed in the diploma thesis of Jan Tauchman. More about this device is discussed in the chapter.

4. LINEAR DRIVES

LINEAR DRIVE SYSTEMS			
MECHANICAL DRIVES	HYDRAULIC DRIVES	LINEAR MOTORS	PNEUMATIC LINEAR MOTORS

Table 1: Basic division of Linear drives[2]

- Mechanical drives are further classified into
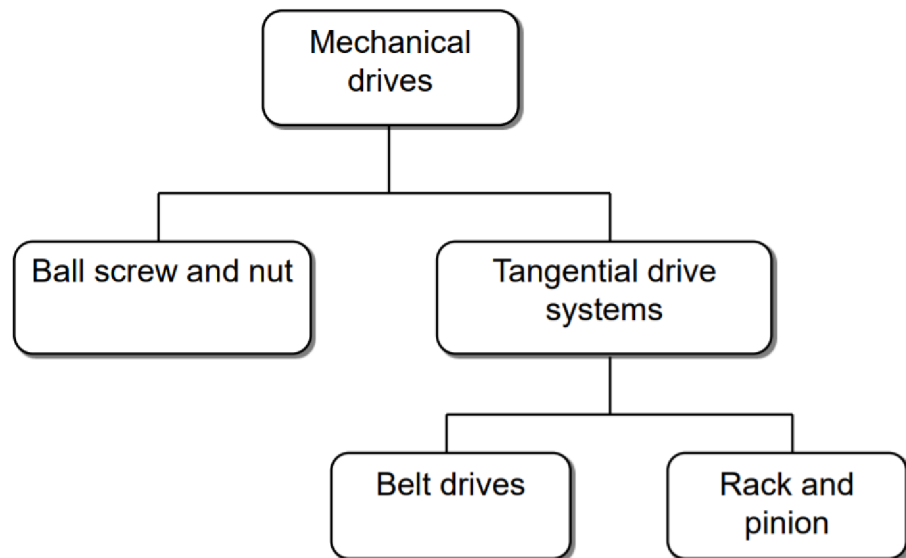
Figure 3: Classification of mechanical drives[2]

5. LINEAR ACTUATORS[3]

A linear actuator is a system that travels in a linear motion between two points. A linear actuator is a mechanism that transforms rotational motion into push or pull linear motion, causing devices or materials to be raised, lowered, slid, or flipped. They have reliable and maintenance-free motion control that is secure and clean.

Electric linear actuators drive the main rod shaft with a DC or AC motor, a row of gears, and a lead screw. The size of the motor determines the difference between actuators. A linear actuator's load power variables are static and dynamic. The sum of force exerted while the actuator is in motion is known as dynamic load power. When the actuator is motionless and holds a load in place, it is referred to as static load power.

Actuators open and shut computer disk drives, shift car seats forward and back, and open and close automatic doors. The fundamental theory of a linear actuator is the idea of an inclined plane, in which the actuator's lead screw moves over a narrow rotational force ramp.

5.1. TYPES OF LINEAR ACTUATOR WHICH CAN BE INSTALLED[3]

Linear actuators are available in a number of configurations to accommodate any use, environment, or industry. The mechanical drive mechanism, reference, and housing are used to identify them.

1. Mechanical or Electro-mechanical Actuators.
2. Hydraulic Actuators.
3. Pneumatic Actuators.
4. Linear motor.

5.2. COMPONENTS OF A LINEAR ACTUATOR[3]

1. Power source.
2. Power converter.
3. Actuator.
4. Mechanical load.
5. Controller.

6. MECHANICAL OR ELECTRO-MECHANICAL ACTUATORS

Mechanical and electromechanical linear actuators are often used to transform rotary motion into linear motion. The difference between mechanical and electromechanical linear actuators is whether they are operated internally or externally, such as by an engine, or manually. The screw (ball-screw, roller screw, or lead screw designs) drives the screw shaft in a straight line by spinning the nut; the wheel and axle, which produces linear motion around a rope, chain, cord, or rack by rotating a wheel; and the cam, which produces linear motion by rotating an eccentrically shaped circle.[4]
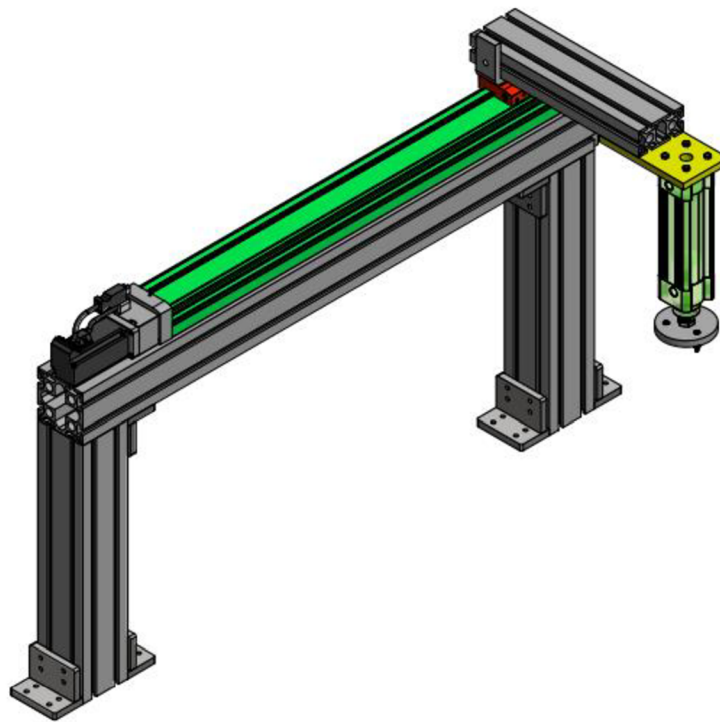
Figure 4: Mechanical Linear actuator

This is a simple manipulator designed by me for my semester work and this better explains the mechanical linear actuator. This is a mechanical linear actuator which helps us to move the object from one position to another in X-direction and Y-direction for 600 mm and 100 mm respectively. All the parts were taken from the FESTO catalogue. This includes Linear drive with the motor assembly and pneumatic cylinder and gripping jaws for holding the object.

7. HYDRAULIC ACTUATORS[5]

Hydraulic Actuators are hydraulic cylinders with a piston that generate linear displacement by applying unbalanced pressure to the piston. Hydraulic actuators are typically used where a significant amount of force is needed to open a valve (for example, the main steam system valves). Figure 3 depicts a conventional piston-type hydraulic actuator. A cylinder, piston, spring, hydraulic supply and return line, and stem make up the system.

The piston divides the cylinder into two chambers by sliding vertically within it. The spring is kept in the upper chamber, while hydraulic fluid is kept in the lower chamber.
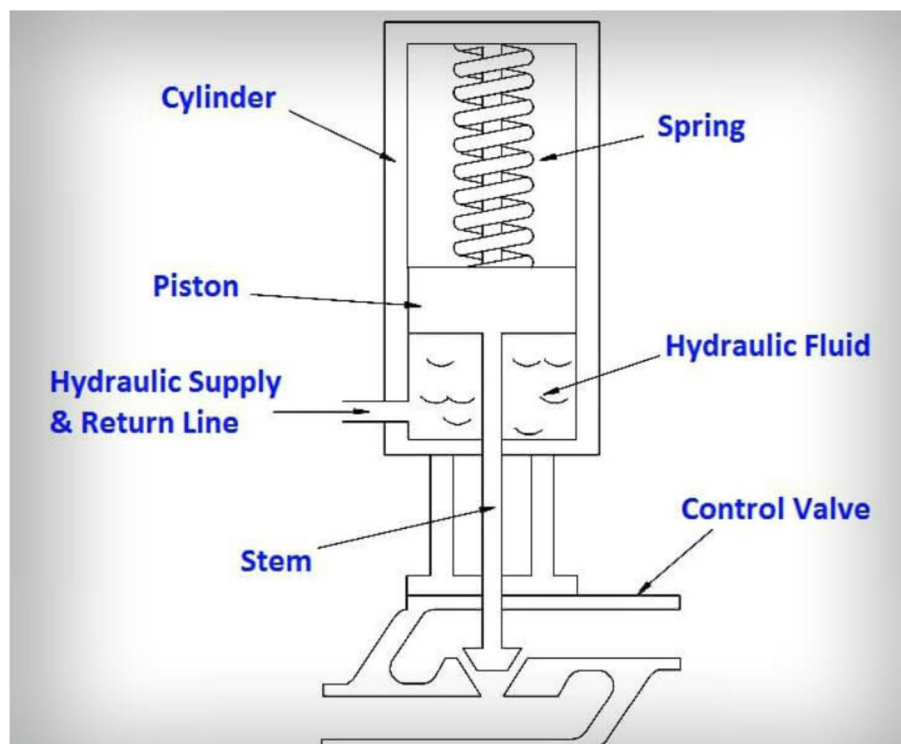
Figure 5: Hydraulic actuator [5]

7.1. FUNCTIONS OF A HYDRAULIC ACTUATOR[5]

The hydraulic supply and return line are attached to the lower chamber of the actuator, allowing hydraulic fluid to flow to and from it. The piston's motion is transferred to a valve through the stem. The spring force keeps the valve in the closed position while there is no hydraulic fluid pressure. If more air reaches the lower chamber, the pressure within it rises.

This friction causes a strain on the bottom of the piston that is the polar opposite of the spring's force. The piston continues to travel upward as the hydraulic force reaches the spring force, the spring compresses, and the valve opens.

The valve begins to open as the hydraulic pressure rises. The hydraulic force becomes weaker than the spring force as hydraulic fluid is withdrawn from the cylinder, the piston travels downward, and the valve shuts. The valve may be located either fully open and fully closed by controlling the volume of oil supplied or drained from the actuator.

The function of a hydraulic actuator is similar to that of a pneumatic actuator. To move the valve, each uses some motive force to counteract spring force. Hydraulic actuators may also be programmed to fail-open or fail-close as a fail-safe feature.

8. PNEUMATIC ACTUATOR[6]

Pneumatic actuators are profoundly solid, productive and safe wellsprings of movement control that utilization compressed air or gas to change over energy into rotational or direct movement. They're particularly proper for the continued opening and shutting of valves and other mechanical applications where the utilization of power may cause a fire or start danger. Pneumatic In the chemical and process industries, actuators are widely used to monitor the valves that guide the flow of fluids.

Pneumatic actuators are also referred to as pneumatic tubes, air cylinders, or air actuators. - of this terminology is interchangeable and they both refer to a system that works with air pressure. Pneumatic ram is another term for an air cylinder, with the ram corresponding to the linear piston.
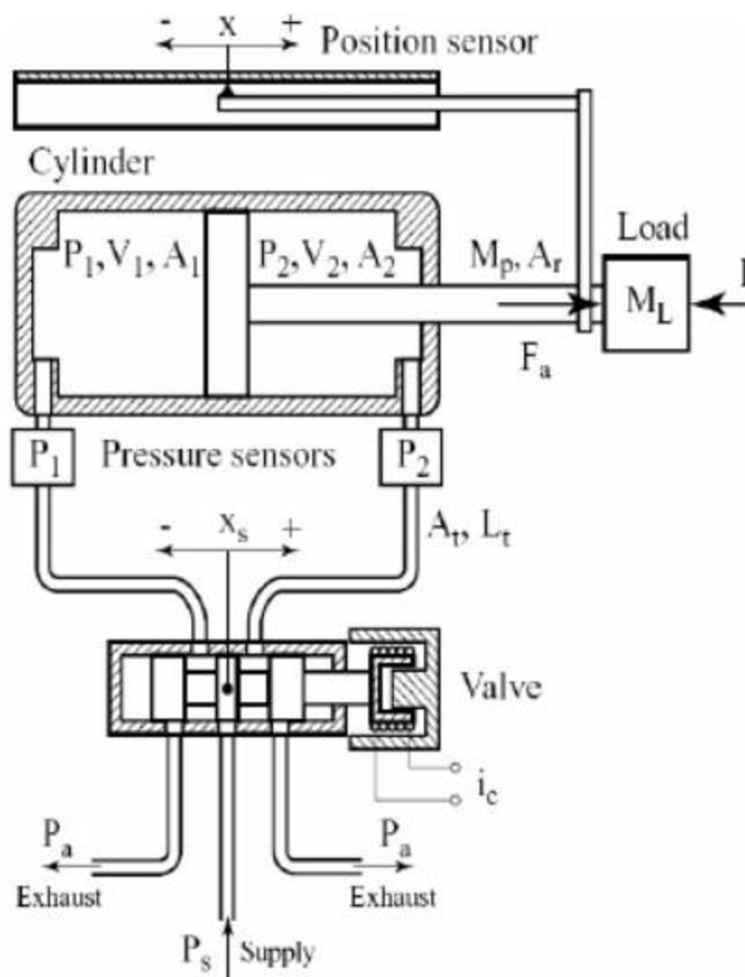
Figure 6: Pneumatic actuator [7]

8.1. WORKING OF A PNEUMATIC ACTUATOR[6]

Pneumatic actuators rely on a pressurized gas — most commonly compressed air — entering a chamber and building up pressure. It results in the regulated kinetic acceleration of a system such as a piston or gear when it has built up enough pressure in relation to the outside air pressure. This subsequent development can be coordinated in either a straight line or roundabout movement.

Since the change of packed gas into energy can be profoundly controlled and is solid and repeatable, pneumatic actuators are quite possibly the most famous mechanical gadgets utilized in a wide exhibit of present-day enterprises.

8.2. TYPES OF PNEUMATIC ACTUATORS[6]

There are two essential assortments of pneumatic linear actuators.

1. Single-acting pneumatic actuators.
2. Double-acting pneumatic actuators.

8.2.1. SINGLE- ACTING PNEUMATIC ACTUATORS
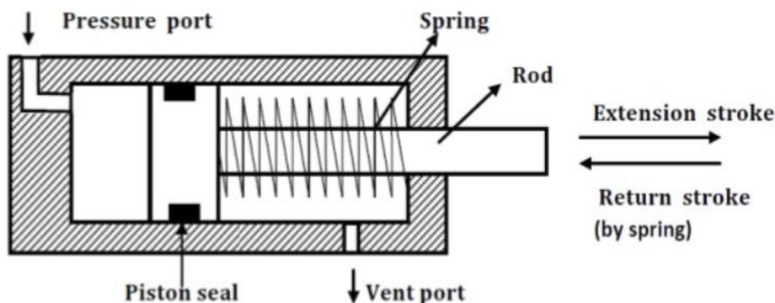
Figure 7: Single acting pneumatic actuator [8]

Because a single-acting hydraulic cylinder is simpler, it requires less maintenance. With only one line, the cylinder's motion is solely governed by the pressure on that one line. They usually use a spring or something similar to push or retract the piston rod, although they might also use the force on the end to do so. Simplicity is usually a good thing when it comes to equipment that has to be tough and dependable.[8]

21

8.2.2. DOUBLE- ACTING PNEUMATIC ACTUATORS[8]
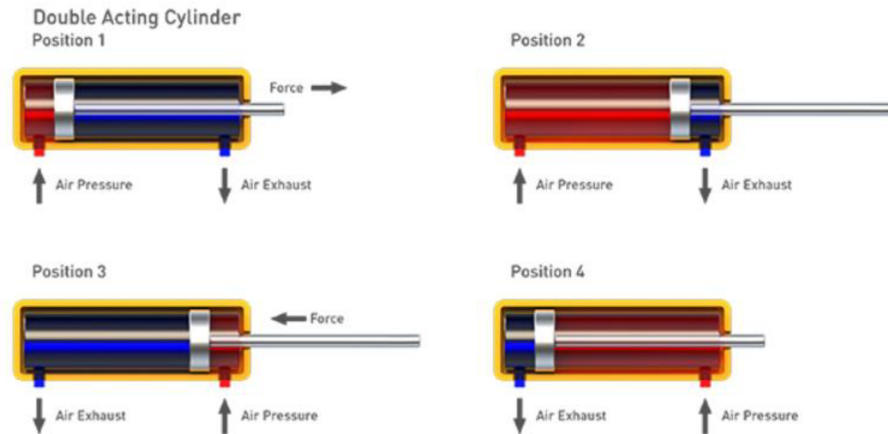
Figure 8: Double acting pneumatic actuator[8]

A double acting cylinder alternates cycles of pressurized fluid to both sides of the piston, creating extend and retract forces to move the piston rod, allowing for more control. To obtain the needed movement for your application, a control system consisting of a 2-, 3-, or 4-way position valve would be necessary.[8]

8.3.   SINGLE-ACTING OR DOUBLE-ACTING PNEUMATIC ACTUATOR

When it comes to deciding which sort of cylinder to use, it all boils down to how much control you require against how much you can pay. A single acting hydraulic or pneumatic cylinder may be your best choice if the heavy lifting is only in one direction. It's ideal to use a double acting hydraulic or pneumatic actuator if you're moving a part in two directions and require complete control.

9. RACK-AND-PINION ACTUATOR

A rack and pinion linear actuator consist of a circular gear (the pinion) engaging a linear gear (the rack), which work together to convert rotational motion into linear motion. When the pinion is rotated, the rack is operated in a linear fashion. The pinion would be driven into rotation if the rack is driven linearly. Straight and helical gears can be used with a rack and pinion drive. Helical gears are favored because they are quieter and can carry more weight. The tooth pitch and pinion size define the overall force that can be transferred in a rack and pinion mechanism.[9]
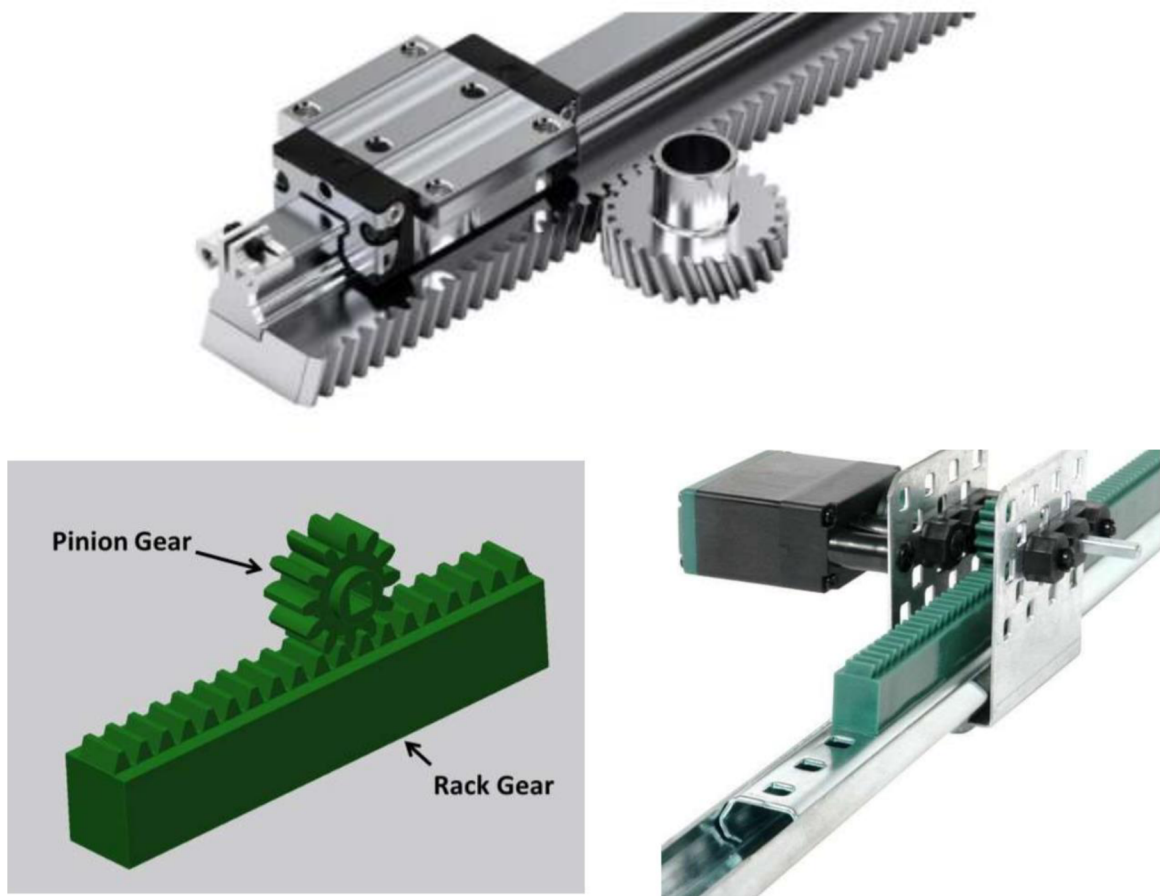
Figure 9: Rack and pinion actuator[10]

9.1. DESIGN OF RACK AND PINION ACTUATOR

Gear racks are used in linear guides in one of two ways: the gear teeth are machined directly into the profiled rail, or the rack is designed to enable the rail to be mounted directly on the rack. While the integrated configuration is more lightweight and easier to assemble,

having the gear rack and profiled rail supplied separately has the advantage of allowing each part to be replaced separately if one is compromised. This reduces maintenance time and costs while also making replacement component stocking easier.[10]

Helical teeth are used in the bulk of profiled rail rack & pinion assemblies because they are quieter and have a higher load volume. Straight cut gears, on the other hand, are available from some suppliers and need less lubrication and are easier to mount. Almost all profiled rail rack & pinion assemblies are made with a pressure angle of 20 degrees, regardless of tooth design. The load carrying power, noise, and backlash behavior of the gear are all influenced by the pressure angle. Because of its high load capability, the 20-degree pressure angle was chosen.[10]
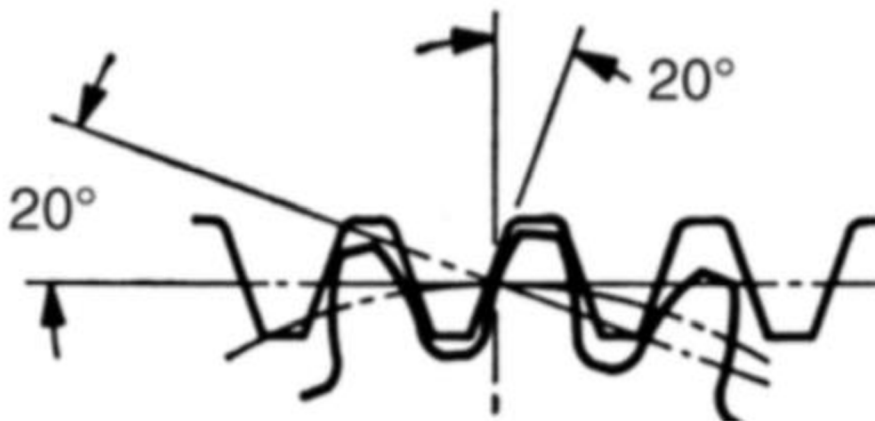
Figure 10: Integrated profiled rail rack & pinion assemblies are typically designed with a 20-degree pressure angle[10]

10. LINEAR MOTOR

In this paragraph, we will discuss about the non-contact linear drive which works under the influence of a permanent magnetic force. Easy processing, no lubrication, no noise, no friction energy, no pollution, low starting torque, and overload protection are all advantages of non-contact permanent magnetic drive technology. The linear motor has been widely employed in different NC equipment, including a laser cutting machine, as a novel driving system.

10.1. WORKING OF A LINEAR MOTOR DRIVE

The track, or fixed component, of the linear motor has a sequence of permanent magnets arranged side by side along its length, while the moving component has electrical windings. When current passes through the windings, the generated magnetic field interacts with the field produced by the track's magnets, generating motion. By simply adding more fixed portions to the motor, you may extend its length. The linear motor in one machining application was 100 feet long.[13]

Figure 11: Linear motor drive[14]

Manufacturers provide a wide range of linear motors, both big and tiny, with a variety of technologies and capacities.

To begin, the linear motor provides the following benefits,[15]

- There is no mechanical contact, the transmission occurs in the air gap, and there is no direct wear on the driving component.

- The stroke is theoretically limitless, and modifications in the itinerary have no effect on performance.

- It has a broad range of speed capabilities, ranging from a few micrometers to several meters per second, with the high speed being a significant benefit.

- The acceleration is significantly large.

- High accuracy and consistency. Because the intermediary connection has been removed, the system's accuracy is dependent on the position detecting element. The precision of the final operation can be sub-micron with the right feedback device. In the realm of laser precision cutting, this characteristic has been widely exploited.

Because of the benefits of linear motors, this type of laser machine is commonly used to set industry records for linear motor speed and acceleration.

11. THE FUNDAMENTAL OF A BALL SCREW[16]

Ball screws climb to the top of the class of all the screws used for industrial motion control, providing many benefits over other alternatives, such as roller screws and acme screws. Ball screws are one of the most inexpensive methods of translating rotary motion into precision linear motion, with efficiencies of at least 90 percent. With excellent precision, they are able to transfer large loads at high speeds. Moreover, pneumatic and hydraulic actuators may be cost-effective alternatives to ball screws.

In order to choose the right ball screw and nut for a particular application, specification variables such as loads, life expectancy, speed, weight, and mountings should be considered by engineers. Lubrication and atmosphere are used in application requirements.
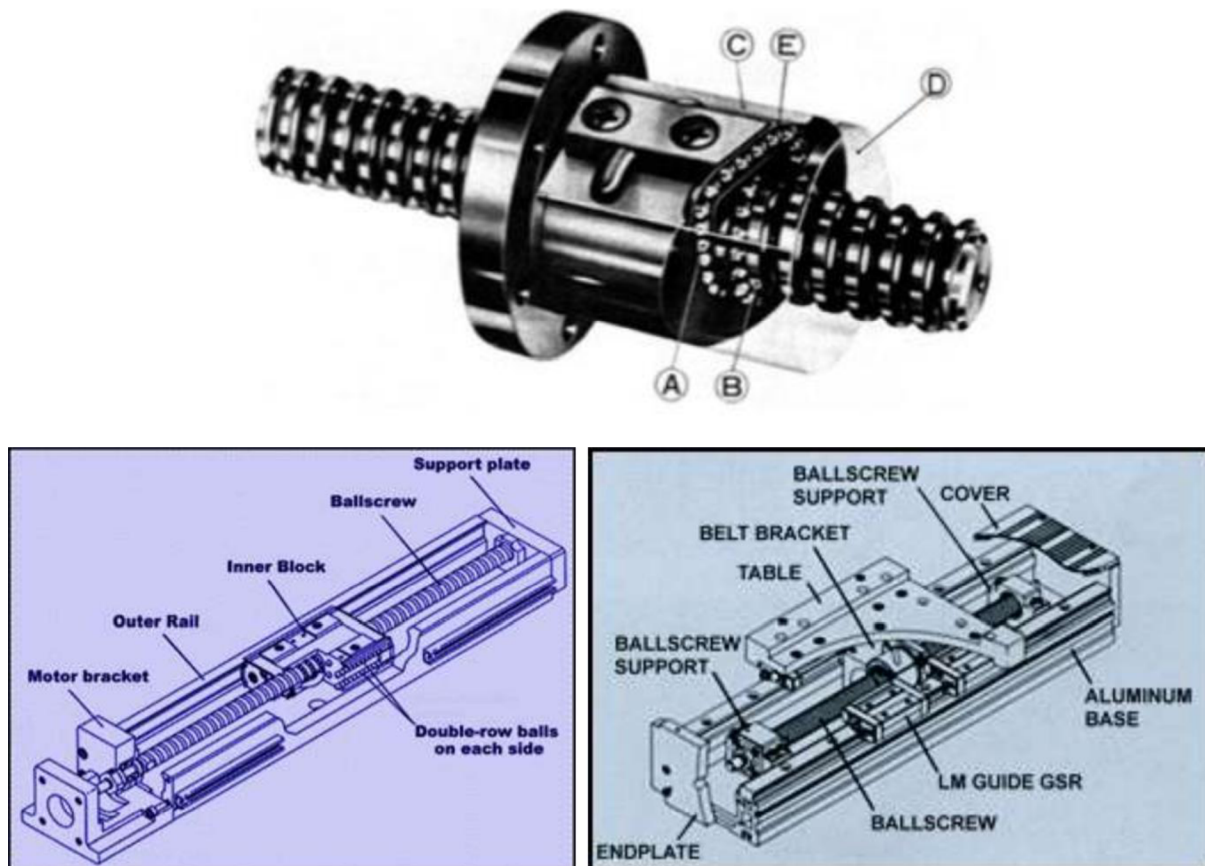
Figure 12: The main components of ball screw[17]

Whereas, A= steel ball, B= Screw shaft, C=Ball nut, D= Seal, E= Recirculation part.

12. COMPARISION OF LINEAR ACTUATORS

The main objective in here is to compare the linear actuator which has been explained above and compare them based on different parameters which can be really ideal to apply on laser cutting machine. While working on the thesis, I came up with different solutions and ideas of linear actuator to apply on the laser machine. It helped me realize what and all advantages and disadvantage that the specific type of linear actuator has got which helped me pick the ideal and the optimum one.

The parameters used to compare Linear actuators,

- Maximum force
- Maximum acceleration
- Maximum speed
- Accuracy
- Repeated Accuracy
- Stroke length
- Cost
- Maintenance frequency

To choose a linear actuator for the assemble on to the laser cutting machine, we need to consider the force which we will be required the cutting process and also, the maximum speed to which the linear actuator can be driven. The next major parameter which has to be taken into account is the accuracy that the linear actuator can run with. Since, complicated shapes are to be produced using a laser cutting machine, it is important to choose the linear drive with which we can achieve greater accuracy.

DRIVE TYPE	BALL SCREW	BELT DRIVE	PINION AND RACK	LINEAR MOTOR	PNUEMATIC LIN. MOTOR	HYDRAULIC DRIVE
Max. force (N)	3000	5640	2000	20000	4000	4500
Max. Acceleration (m/s^2)	15	40	10	200	n	n
Max. speed (m/s)	3	8	2	11	5	3
Accuracy (μm/25.4mm)	7.6	25 ÷ 50	0.6 ÷ 4.2	0.2 ÷ 0.7	n	n
Repeated accuracy (μm)	10	12 ÷ 300	n	0.1 ÷ 30	25 ÷ 150	n
Stroke length (m)	0.2 ÷ 5.3	0.3 ÷ 8	0.3 ÷ ∞	$0.25 \cdot 10^{-3}$ ÷ ∞	0.01 ÷ 6	0.01 ÷ 6

Whereas, n- Couldn't identify

Table 2: Comparing the parameters of Linear drives[2]

12.1. ADVANTAGES AND DISADVANTAGES OF LINEAR DRIVES

These are the standard parameter and advantages and disadvantages which we got to look at before choosing a linear drive for the laser machine. And now, we shall take a look at the ball screw linear drive since we are using the ball screw linear actuator because it suits the parameter and also because of its advantages and disadvantages.

LINEAR DRIVES	ADVANTAGES	DISADVANTAGES
BALL SCREW	• Large load • High accuracy	• High inertia • Small velocity and small acceleration
BELT DRIVE	• Larger speed and acceleration • Low price	• Small loads • Small accuracy
PINION AND RACK	• High accuracy • Infinite length • Low price	• Small loads • Low speed and low acceleration
LINEAR MOTOR	• High load • High speed and high acceleration • High accuracy • Unlimited length • No additional moving parts	• High production costs • Required coolant supply • Open magnetic structure
PNUEMATIC LINEAR MOTOR	• Simple	• Small loads • Small accuracy

Table 3: Advantages and disadvantages of Linear drives[2]

13. OVERVIEW OF THE MACHINE ON THE MARKET

It is beneficial to be influenced by or specifically dependent on the latest state of technology and its business offerings in all design practice. As a result, examples of machines with identical purposes or design or their linear drives to the proposed machine would be discussed in the following paragraphs. It will be identified alongside laser cutting machines as well as examples with modeling milling machines of similar constructions since it can not only be used for laser processing (cutting) of boards, but it is also presumed potential spindle mounting for milling.

13.1. TYPES OF MILLING MACHINES AND THEIR DRIVE SYSTEMS

Under this, we shall take a look at the different type of milling machine and the type of drive system which is commonly used which will help us understand what can be used on the project.

13.1.1. CAM 1520 Premium

High rigidity and precision (repeated positioning accuracy: 0.01 mm) describe this modeling milling machine from the German company vhf camfacture AG. The Y axis is supported by a portal made of linear units with backlash-free ball screws and double linear guidance, with two parallel units. 1550×2010×490 mm is the positioning range. The use of high-strength aluminum profiles as the foundation ensures high rigidity, low weight, and high load power. A sturdy table made of profiles with T-slots allows for simple clamping of workpieces and accessories. The computer is particularly useful in challenging manufacturing applications like wood, plastics, and metal machining, as well as creation forms and rapid prototyping.[18]

13.1.2. FlatCom M50

The FlatCom M50 model milling machine, manufactured by Germany AG in Germany, is built using special aluminum profiles that have strong rigidity while remaining light. The axes are arranged in a portal pattern here as well, with the Y axis being doubled and positioned at the level of the desk. The portal is connected to the longitudinal axis X by stands, resulting in a direct height of 300 mm. The actual axes have a movement length of 1200×1400 ×250 mm.

The linear axes 16 mm and 10 mm are positioned using backlash-free ball screws that are operated by maintenance-free EC servomotors. As a result, at a machining speed of 15 m/min, the unit achieves repetitive positioning precision of 0.02 mm. The milling machine can be used to make concept templates, architectural models, aluminum front panels, and advertisements, among other things.[19]

Figure 13: FlatCom model milling machine[18]

13.1.3.   GPY 138/158

Many implementations necessitate a computer concept that is universal on the one side, but still allowing for lengthy travels to process vast areas on the other. That's what the German firm imes-icore GmbH's model milling machine GPY 138/158 has to sell. A double Z axis with a wide direct height portal distinguishes this CNC machine. This distinguishes it from other devices of the same kind, which usually have one Z-axis fixed on a longitudinal trolley X-axis, to which the milling spindle is then attached. Aside from that, the construction is standard - sturdy, constructed of aluminum profiles, and built in an industrial style.

The axes have a positioning length of 1380×1580×580 mm. Both axes' servomotors and ball screws with a diameter of 16 to 5 mm are operated by AC. Positioning accuracy is 0.02 mm over time. The normal feed rate is 8 m/min, but it can be increased to 25 m/min if required. Rapid prototyping, the construction of big and design models, the processing of wood, laser digitization, copy milling, and so on are just a few of the applications for these

devices. Aluminum, wood, plastics (ABS, polystyrene), and gypsum are among the materials that the milling machine will process.[20]
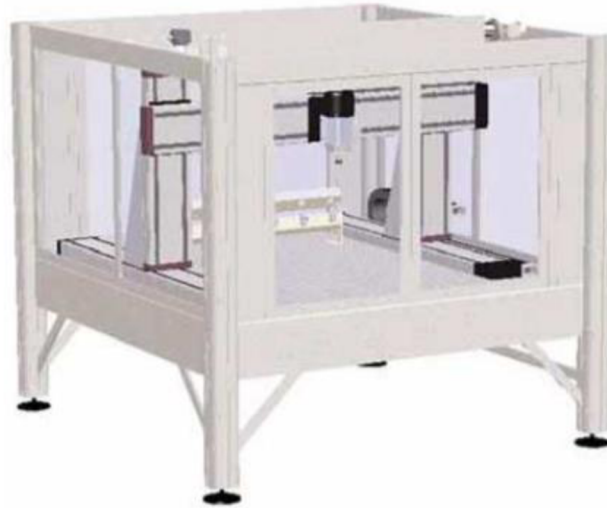
Figure 14: Modeling milling machine of the GPY series with a protective cover[20]

13.1.4.   COMPARISION OF THESE MILLING MACHINES

MACHINE	WORKING RANGE	FEED RATE	ACCURACY	DRIVE TYPE
CAM 1520 Premium	1550×2010×490 mm	-	±0,01 mm	Ball screw
FlatCom M50	1200×1400×250 mm	15 m/min	±0,02 mm	Ball screw, EC
GPY 138/158	1380×1580×580 mm	8- 25 m/min	±0,02 mm	Ball screw, AC

Table 4: Comparison of Milling Machines

13.2. LASER CUTTING MACHINES

Under this, we shall take a look at the different type of Laser cutting machine and the type of drive system which is commonly used which will help us understand what can be used on the project.

13.2.1. TruLaser 1030

TRUMPF's computer is distinguished by its low investment and maintenance costs, ease of use, and compact footprint (only 25 m^2). TruCoax is a cutting 2kW diffusion cooled CO2 laser. TruLaser 1030 can cut structural steel up to 15 mm thick (stainless steel 6 mm, aluminum 5 mm) with a simultaneous axis speed of 85 m/min. The unit axes have a working length of 3000×1500×75 mm. The machine is ideal for beginners who wish to take on previously outsourced jobs or who want to move from solid to sheet metal for cost purposes. Its versatility allows for short-term development, shift testing, and prototype design. The TruLaser 1030 can also be used as a low-cost training unit.[21]

Figure 15: TruLaser1030[21]
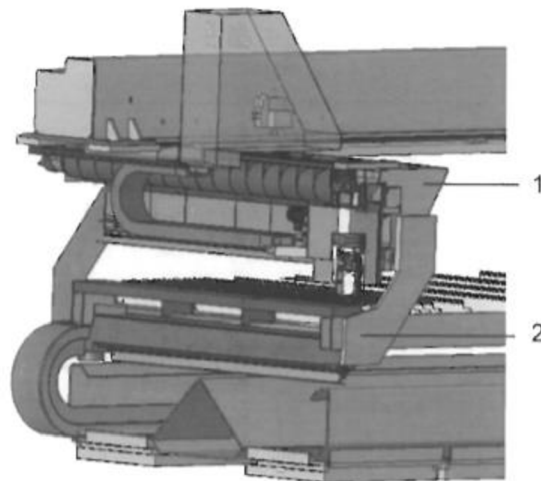
Figure 16: Movement unit with catcher[22]

Whereas,

    1- Movement unit

    2- Catcher

The Y and Z axes, as well as the X axis motor, are carried by the movement unit linked to the crossbeam. The traversing motions are carried out using rack and pinion systems.

13.2.2. PROFILE PLUS 3015

This CNC unit is the company Farley Laserlab's third generation of laser cutting devices. It is extremely dependable and efficient, with comparatively low maintenance requirements. It features a Sinumerik 840D advanced control system with a handheld control screen. The cutting head is fixed on a cast frame of high-quality linear guides and is mounted on an extremely robust self-supporting limb.

Figure 17: PROFILE PLUS 3015[23]

The machine's operating surface is illuminated and has dimensions of 3050 x 1500 mm. Precision drives ball screws make for a maximum movement speed of 50 m/min in the X and Y axes (and 10 m/min in the Z axis), with a maximum cutting speed of 9 m/min for steel and 30 m/min for paper. It achieves 0.02 mm repeatability in positioning.[23]

13.2.3. M-1600

The German company Euro-laser GmbH's laser cutting machine M-1600 produces excellent cutting performance. Engraving is also not a challenge for this method. Since the laser system is built on a modular basis, all critical components can be replaced. The work table can be divided into two parts with dimensions of 1300 x 1600 mm.

It is now possible to cut or engrave material in the front section of the table while simultaneously removing processed material or creating new ones from the back pieces, greatly increasing the efficiency of the machinery. The high-quality CO_2 laser source needs almost no upkeep. His power output will range from 60 to 600 watts. Cutting speeds of up to 60 m/min are possible. The system will cut a variety of materials, including wood, textiles, acrylic resins, and foils.[24]

Figure 18: M-1600 machine type[25]

13.2.4.   SALVAGNINI L3-30

Salvagnini L3-30 is a laser cutting system from Salvagnini, an Italian firm that is a world pioneer in the production of extensive sheet metal processing solutions. In comparison to traditional CO2 lasers, the fiber laser used in this machine has a range of advantages. Optical paths and laser gas are not needed here, and maintenance is minimal. When compared to CO2 lasers, energy savings was up to 75%. It also encourages you to cut materials that are highly translucent, such as brass or 20 copper (up to 5 mm thick). Structural steel can be cut to a maximum thickness of 15 mm, stainless steel to a maximum thickness of 10 mm, and aluminum to a maximum thickness of 8 mm.

The work table is 3048 x 1524 mm in dimension, with a 100 mm stroke on the Z axis. The support arm theory adds to the rigidity of the structure which allows for quick and precise placement as well as convenient access to the workpiece. The overall positioning speed is up to 120 m/min, and the repeat positioning precision is 0.03 mm.[26]

Figure 19: SALAVAGNINI L3-30[18]

13.2.5.   FLEXI SERIES

Flexi Series are more effective and have market prospects in a variety of sectors, including railways, automobiles, energy, defense and aerospace, home appliances, gym equipment, and kitchenware, to name a few.

FEATURES

- Durable Rack-Pinion motion system.
- Lightweight gantry with coordinated dual servo motors for high dynamics.
- Auto focus cutting head.
- Dust proof gas line for gas flow.[27]

ITEM	SPECIFICATIONS
MOTOR X	3050 mm SIL Brand
MOTOR X1	3050 mm SIL Brand
MOTOR Y	1520 mm SIL Brand
Z axis	150 mm
Position accuracy	≤ ± 0.05 mm
Repeated accuracy	≤ ± 0.03 mm
Maximum rapid speed	80 m/min
Cutting speed	20 m/min

Table 5: Specification table for FLEXI series [27]

Figure 20: FLEXI series[27]

13.2.6.   VANAD KOMPAKT LASER

The Vanad KOMPAKT Laser CNC machine allows for incredibly precise, rapid, and efficient thermal cutting of materials. Because to its design, it may be used in small, medium, and large operations, as well as for pre-production series. The highly concentrated laser beam enables for common line cutting of the material due to the minimal kerf and low heat effects on the material.[28]
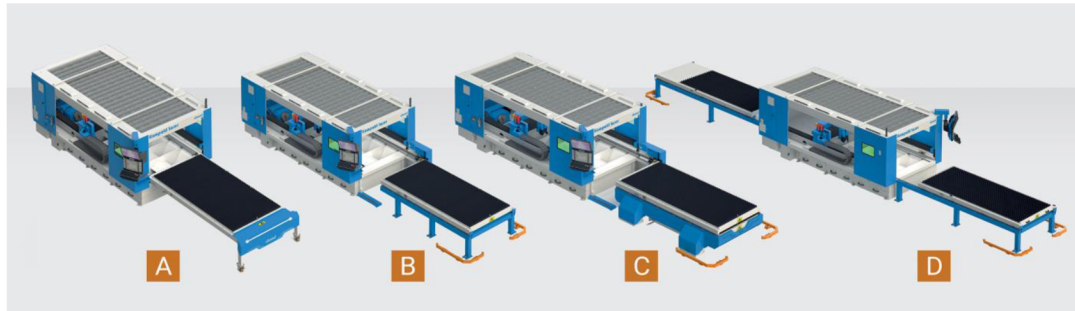
Figure 21: Models of material grids for Vanad KOMPAKT Laser[28]

Whereas,

A- Manually extendable grid

B- Motor-power extendable grid

C- Two hydraulically exchangeable grid

D- Two manually extendable grid

FEATURES OF VANAD KOMPAKT LASER[28]

- The fiber laser is the most popular form of laser. It has an incredible endurance of up to 100 000 hours.

- Although it has the same efficiency as a CO2 laser, it consumes substantially less energy, resulting in cheaper running expenses.

- Its robust structure makes it simple to build and carry.

- It can also carve complicated forms with precision.

13.2.7. RAPIDO (PRIMAPOWER)

RAPIDO has a fiber laser source with varying strengths depending on the type of production. In the event of big series manufacturing, the high brightness fiber laser with high energy efficiency, eco-compatible use, and no maintenance provides the best results. This source is used by many applications, yielding in shorter cycle times and cheaper cost per part.[29]

Figure 22: RAPIDO machine type[29]

13.2.8.   KIMLA LASER FIBER CUTTER

Figure 23: KIMLA Laser Cutting Machine[30]

13.2.9. COMPARISION OF LASER CUTTING MACHINES

NAME OF THE MACHINE	WORKING RANGE	FEED RATE	ACCURACY	LASER TYPE	DRIVE TYPE
TruLaser 1030	3000×1500×75 mm	85 m/min	-	CO_2	Rack and Pinion
Profile Plus 3015	3000×1500 mm	50 (10) m/min	±0.02 mm	-	Ball screw
M-1600	1300×1600 mm	60 m/min	-	CO_2	-
Salvagnini L3-30	3048×1524×100 mm	120 m/min	±0.03 mm	Fibrous	-
FLEXI SERIES	3050×1520×150 mm	80 m/min	0.05 mm	IPG / Raycus	Rack and Pinion
VANAD KOMPAKT LASER	2000×6000mm	45.3 m/min	-	Fibrous	-
RAPIDO	4080×1530×765 mm	100 m/min	± 0.012 mm	Fibrous	-
KIMLA LASER FIBER CUTTER	2500×12000×100 mm	250 m/min	±0.02 mm	Fibrous	Induction linear motor

Table 6: Comparison of Laser cutting machines

14. CHOOSING THE DRIVE TYPE

From the above milling and laser machines, it can be that many of industries are preferring ball-screw drive since it is much reliable. Also, that it can withstand large loads and it also has higher accuracy as compared to hydraulic and pneumatic drives. Hydraulic and pneumatic drive type cannot be used in laser machine since it becomes much difficult to provide complex shapes with those drive types. Also, they can only withstand small loads.

And also, we know that the existing laser machine in the laboratory uses ball screw drive type and the main aim is to increase the feed rate so that the productivity can be achieved. For to improve the feed rate, it is necessary to concentrate on the parameters which is going to help us achieve the result.

 Also, there is another major to look on. If it is feasible and economical enough to just change the components which has to be changed with respect to new design changes and if it will be the other way by replacing the whole of linear actuator. And if that's the case, we can also come up with other variants of drive types. From the above studies and comparisons, it is seen that rack and pinion drive type and linear motor seems much reliable. Linear motor can withstand high loads and they are contactless actuator which makes us easy for the maintenance since there won't be much friction happening. There are also no additional moving parts. So, the variants are,

VARIANT 1- Ball screw drive type with increased feed rate
VARIANT 2 - Linear motor.

Figure 24: VARIANT 1[31]   **Figure 25: VARIANT 2**[32]
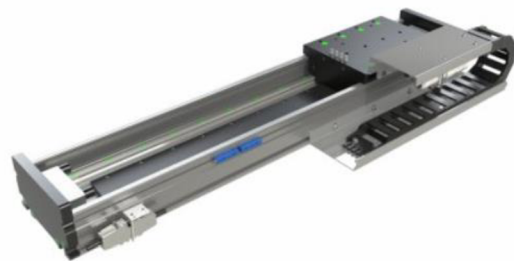
15. PARAMETERS USED IN CALCULATING BALL SCREW

- Diameter (d)

- Length (l)

- Pitch (p)

- Co-efficient of end support bearing (k_d)

15.1. Diameter:

As they come into contact with both the screw and nut, the ball circle diameter is the diameter of the circle formed by the center of the ball bearings. The minimal screw diameter measured at the bottommost point of the threads is the root diameter. When measuring application characteristics and sizing parameters for variables such as column loading and critical, both diameters are important.[33]
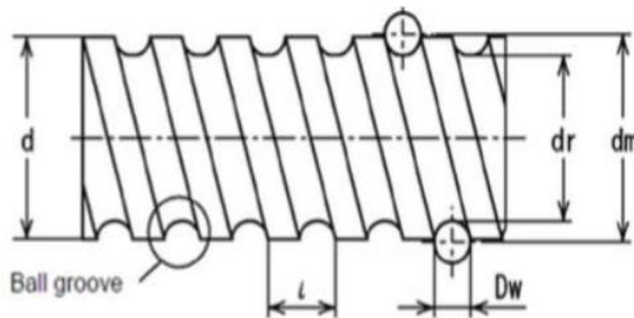
whereas,

d= Screw shaft diameter

d_m= pitch circle diameter

d_r= root diameter

l= lead

d_w= ball diameter.

Figure 26: Parameters of ball screw[33]

	PARAMETER	RESULT
SCREW DIAMETER increases	Critical Speed	Increases
	Inertia	Increases
	Stiffness	Increases
	Spring rate	Increases
	Load Capacity	Increases
	Column load	Increases

Table 7: Effect of diameter change[34]

15.2. Length:

The length of the ball screw plays a vital role in the complexity of the design. Because if we are altering the length of the screw, then the whole length of the structure has to be changed since the screw length correlates with the support or structure length.

	PARAMETER	RESULT
SCREW LENGTH increases	Critical speed	Decreases
	Critical load	Decreases

Table 8: Effect of Length[34]

15.3. Pitch:

The axial distance on a screw between two consecutive threads is pitch. When one is rotated during one continuous revolution, lead is the linear distance traveled by the nut or screw. The initials are the number of individual threads on the shaft of the screw. Usually, on a screw, there are one, two or four starts, which resemble a helix that coils around the shaft. **Lead:** Lead is the linear travel per one screw revolution that the nut makes which is usually how ball screws are defined.
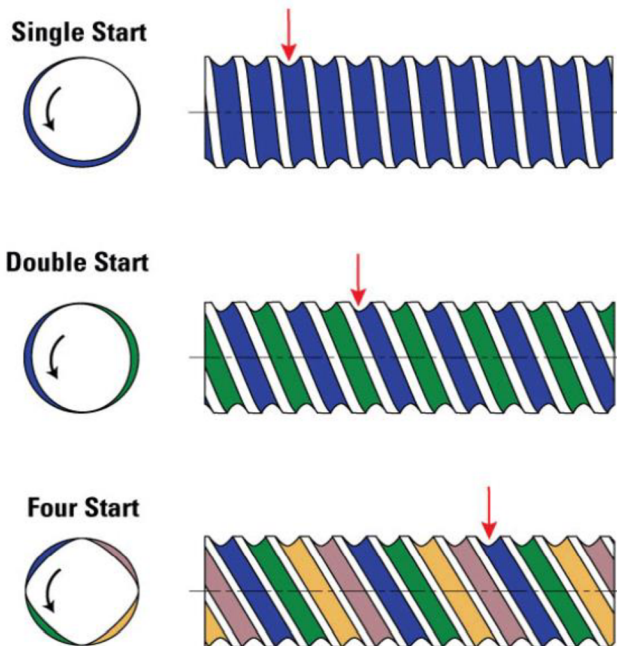
Figure 27: Relation between pitch and lead[35]

	PARAMETER	RESULT
PITCH increases	Torque Input	Increases
	Load capacity	Increases
	Positioning accuracy	Decreases
	Angular velocity	Decreases
	Ball diameter	Increases
	Linear Velocity	Increases

Table 9: Effect of Pitch change[34]

15.4. Co-efficient of end support bearing:

The rigidity, maximum speed and buckling load of screw assemblies are affected greatly by end support bearings. There are two main types of support for a ball or lead screw end that can be implemented: basic (also referred to as floating) and set. With a single ball bearing, which provides protection against radial loads, basic support is obtained. With an angular contact thrust bearing, which counteracts both axial and radial pressures on the screw, fixed support is obtained. When two single ball bearings are installed with a room between them, a third form of support can be accomplished.[35]

15.4.1. End Fixity Condition[35]:
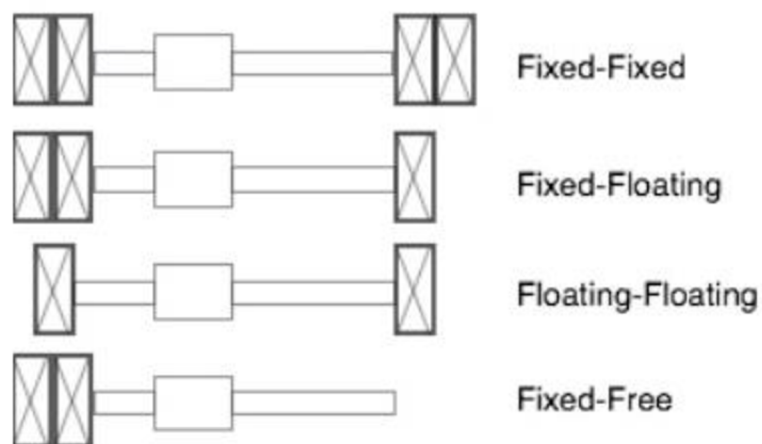
Figure 28: Condition of end fixity[35]

46

15.4.2. End fixity and Screw performance[35]:

Critical speed and buckling load, two parameters of ball screw output, are directly proportional to a factor dependent on the arrangement of the end bearing. For the most rigid support (fixed-fixed), this end bearing component is highest and lowest for the least rigid arrangement (fixed-free).

15.4.3. Determination of K_d Co-efficient:

2.74	1.88	1.22	0.42
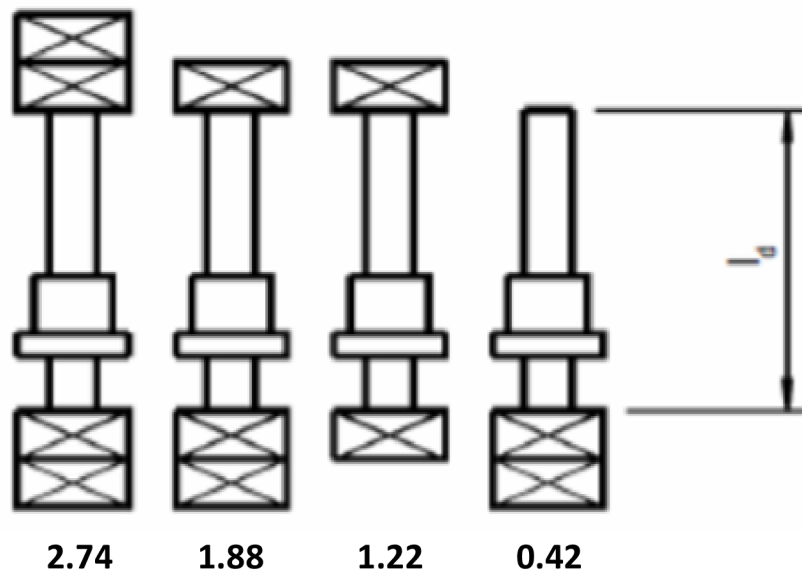
Figure 29: Determination of K_D Co-efficient[18]

According to the one we are using; it has got one radial bearing on either end. So k_d= 1.22.

16. LASER MACHINE IN THE KSA LABORATORY[36]:

The laser system is housed at the KSA laboratory in the building of the Technical University of Liberec. The entire package is made up of many components. The control mechanism takes care of the motion of all servomotors. The control system which is used is Siemens' Sinumerik 840D, which uses SIMODRIVE 611 units, 6SN1123-1AA00-0CA2 Labelled.

Figure 30: SIMODRIVE 611[18]

There is also a GSI JK400FL laser source from the GSI Group. It is a fiber laser with power 400 W with a wavelength of 1070 nm. [37] The laser source is cooled by water, the distribution and cooling of which takes care of TAEevo M03 equipment. The cooling capacity of the device is 1.4 kW at ambient temperature 25°C.[38] The cutting head is from the same company as the laser source (GSI Group)

An optical fiber directs the laser beam from the source to the cutting head. Since the beam is directly produced by the optical fiber, it is important to provide a laser source of at least 100 mm in order not to distort the fiber. The official optical fiber bending radius is 75 mm.

17.STANDARD DIMENSION FOR BALL SCREW[39]

Pitch	0.5	1	1.5	2	2.5	3	4	5	6	8	10	12	15	16	20	25	30	32	35	40	50
Diam.																					
3	•	•																			
5	•																				
6		•	•	•																	
8	•	•		•	•		•	•		•											
12		•		•		•	•	•			•										
16				•			•	•			•										
20				•			•	•			•				•					•	
25				•			•	•			•		•		•	•					•
32							•	•	•	•	•	•	•		•	•	•	•			
36											•										
40								•	•	•	•	•	•	•	•	•	•			•	
50								•			•	•	•	•	•	•	•		•	•	
60															•	•			•	•	
63								•			•		•	•	•						
80								•			•		•		•	•	•			•	•
100											•		•		•		•			•	

Table 10: Standard dimension for BALL SCREW[39]

18.LINEAR UNITS (BALL SCREW)

Linear axes are the basis of the entire construction of the proposed laser cutting machine, which converts the rotational movement of the servomotor shaft into the linear movement of the controlled axis slider. We are here using the Positioning axes of the sequence BSU 160, supplied here by the Czech firm HIWIN s.r.o.. They are designed for less challenging applications with lower drive dynamics, according to manufacturers, and focus on the critical speed of the ball screw used based on the axis length. This are axes of type R16*5 (diameter*pitch of the screw) rolled ball screw. The screw has an IT7 (52 µm / 300 mm) precision. The axes are also fitted with switches for induction terminals and a motor attachment flange.
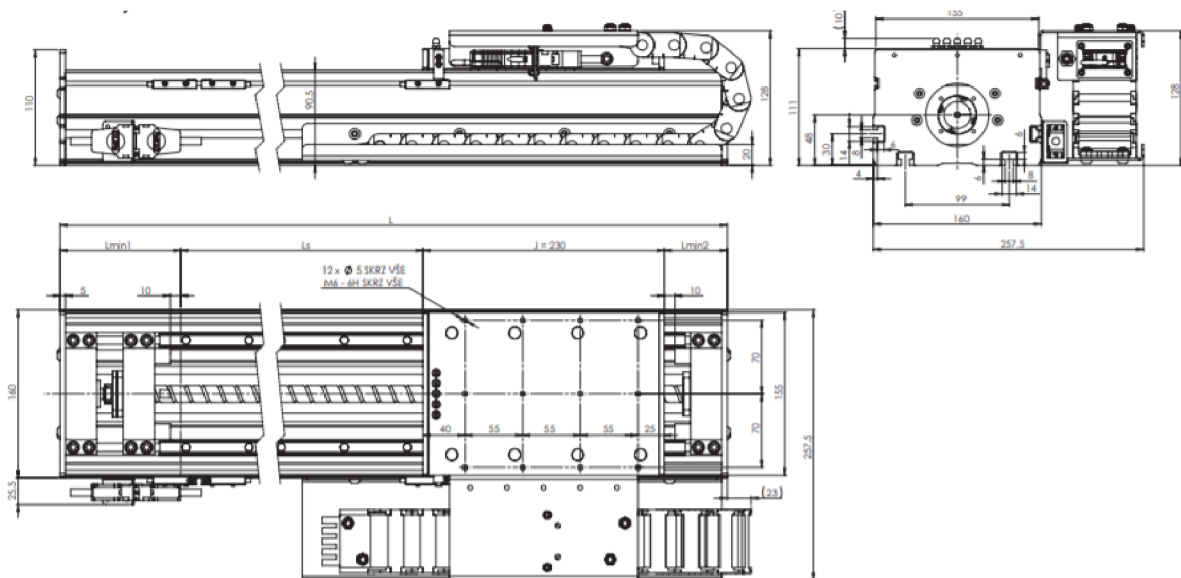
Figure 31: Basic Structure for BALL SCREW Linear units from HIWIN[40]

The linear unit for the X-axis has a maximum stroke of 1700 mm, total length 1850 mm and weight approx. 53 kg. Because it is a portal structure, there are two linear units for the Y axis. They have a maximum stroke of 1200 mm, total length 1550 mm and an approximate weight of 44 kg. A linear unit will be used for the Z axis with a maximum working stroke of 500 mm, a total length of 820 mm and a weight of approx. 24 kg.

19.CALCULATION OF X-AXIS DRIVE:

SPEED OF X-AXIS

Diameter, D_x= 16mm

Length, L_x= 1850mm

Pitch, p= 5mm

Equation reference[36]

$$N_x = k_d . \frac{d}{l^2} . 10^8 = 1.22 . \frac{16}{1850^2} . 10^8 = 570.34 \text{ min}^{-1} \tag{1}$$

The vital speed range for the ball screw can never be exceeded. The size critical speed is determined by the screw's diameter d, mounting distance lk, and storage process. The maximum running speed, n_{max}, does not exceed 80% of critical speed, nk.

$$N_{max(x)} = (0.8)N_x = (0.8)570.34 = 456.2 \text{ min}^{-1} \tag{2}$$

Feed rate, f_x= $n_x.p$ = 456.27(5) = 2281.35mm/min= 2.2m/min. $\qquad$ (3)

We require a feed rate of 6m/min

So, further evaluating and trying different diameters and varying the pitch so that we can achieve a feed rate of 6m/min.

○ Width 160mm
○ Ball screw ø 16 or 20mm
○ Max. up tp 1,7m
○ Accuracy 0,052 or 0,023/300mm
○ Drive - stepper or servo motor, eventually gearbox

Part number	Type screw	Screw accuracy	Max. stroke S [mm]	Max. velocity V1max* [m/s]	Max. velocity V2max* [m/s]	Slider weight [kg]	Weight static. part [kg/0,5m stroke]	CAD
BSU160-01	R16x05	IT7	1200	0,26	0,10	5,5	17	CAD
BSU160-02	R16x10	IT7	1200	0,50	0,19	5,5	17	CAD
BSU160-03	R16x16	IT7	1200	0,84	0,31	5,5	17	CAD
BSU160-04	R16x20	IT7	1200	0,95	0,36	5,5	17	CAD
BSU160-05	R20x05	IT7	1700	0,34	0,13	5,5	17	CAD
BSU160-06	R20x10	IT7	1700	0,67	0,25	5,5	17	CAD
BSU160-07	R20x20	IT7	1700	1,37	0,52	5,5	17	CAD
BSU160-08	DEB16x05	IT5	1200	0,27	0,10	5,5	17	CAD
BSU160-09	DEB20x05	IT5	1700	0,35	0,13	5,5	17	CAD

Figure 32: Selection of BALL SCREW Linear system[40]

Taking BSU160-06,

$$N_x = k_d . \frac{d}{l^2} . 10^8 = 1.22 . \frac{20}{1850^2} . 10^8 = 712.9 \text{ min}^{-1} \tag{4}$$

$$N_{max(x)} = (0.8)N_x = (0.8)712.9 = 570.3 \text{ min}^{-1} \tag{5}$$

Feed rate, f_x = $n_x.p$ = 570.3(10) = 5703.4mm/min= 5.8m/min. $\tag{6}$

20. CALCULATION OF Y-AXIS DRIVE:

SPEED OF Y-AXIS

Diameter, D_x= 16mm

Length, L_x= 1550mm

Pitch, p= 5mm

$$N_y = k_d . \frac{d}{l^2} . 10^8 = 1.22 . \frac{16}{1550^2} . 10^8 = 812.4 \text{ min}^{-1} \tag{7}$$

$$N_{max(x)} = (0.8)N_x = (0.8)812.4 = 649.9 \text{ min}^{-1} \tag{8}$$

Feed rate, f_x = $n_x.p$ = 649.9(5) = 3249.9mm/min= 3.2m/min. $\tag{9}$

We require a feed rate of 6m/min

So, further evaluating and trying different diameters which will give us 6m/min

Taking BSU160-02 from the figure 8,

$$N_y = k_d . \frac{d}{l^2} . 10^8 = 1.22 . \frac{16}{1550^2} . 10^8 = 812.4 \text{ min}^{-1} \tag{10}$$

$$N_{max(x)} = (0.8)N_x = (0.8)812.4 = 649.9 \text{ min}^{-1} \tag{11}$$

Feed rate, f_x = $n_x.p$ = 1299.9(10) = 6499.8mm/min= 6.4m/min $\tag{12}$

21. APPROPRIATE CHANGES DONE TO ACHIEVE THE REQUIRED FEED RATE

The main aim of thesis is to achieve increase the feed rate and provide much more solutions and advancements to the existing Laser machine. For to achieve the required feed rate, we will have to check what helps us increasing the feed rate without disturbing its whole design and make it more complicated. With HIWIN providing us different designs with standard dimensions available in the market, we now know to select the one which helps us achieve the required feed rate according the required length.

Enhancing pace can improve accuracy, but there are a range of hurdles to tackle in order to achieve that optimization. As a consequence, there are two criteria for ball screw high-speed optimization.

- Increase the linear motion distance per rotation. Big leads are used.
- Increasing the rpm simultaneously helps us achieve accuracy

Since an improvement in accuracy is expected at the same time as an increase in ball screw speed, it is important to concentrate on both.[41]

21.1. CHANGES TO BE DONE IN X-AXIS LINEAR ACTUATOR

In the existing laser cutting machine, the speed range of linear actuator is around 570.34 min^{-1} and the feed rate is about 2.2 m/min. The main aim is the increase the federate so that the productivity can be achieved. So, we will have to concentrate on the parameters which is going to help us achieve the required result. From the above calculation, the parameter which is going to help us achieve the required feed rate are diameter of the screw and the pitch. As seen in the above calculation, on increasing the diameter of the screw from 16mm to 20 mm, the speed is increased from 570.34 min^{-1} to 712.9 min^{-1}. Also, we have to take into consideration that this is not the actual speed. The maximum running speed, n_{max}, is not more than 80% of the critical speed, n_k. So, we have to consider the critical speed and with increase in diameter and increase in pitch, the necessary feed rate has been achieved.
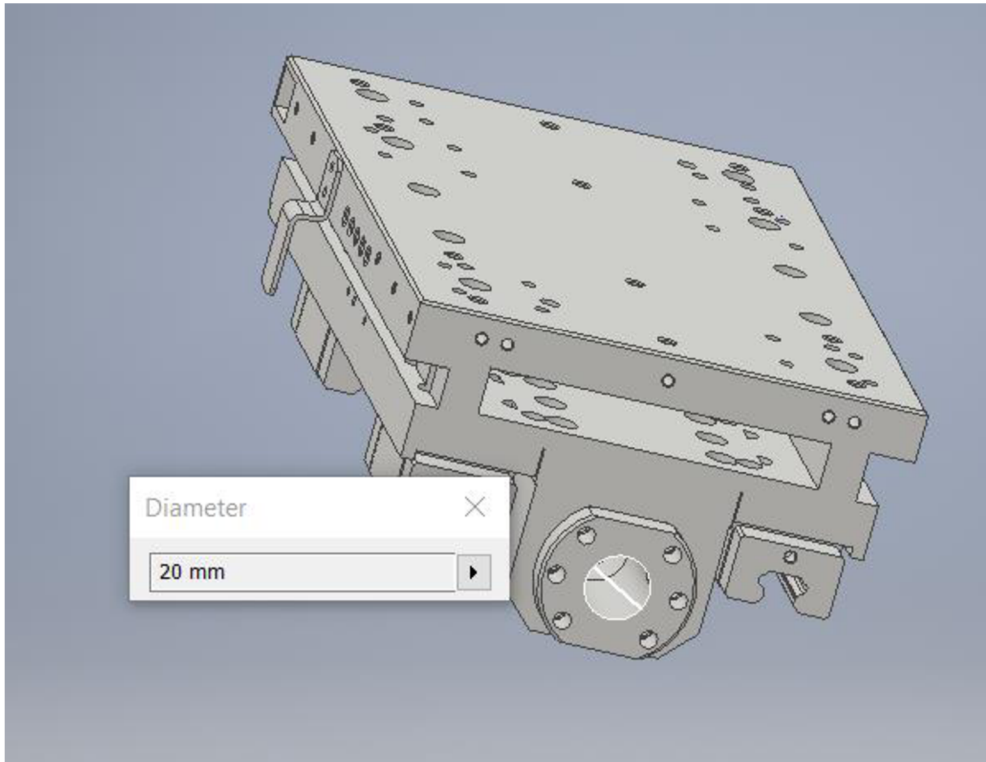
Figure 33:Ball screw diameter X-axis actuator

As seen in the Figure 33, the diameter of the LM where the screw travels are increased to 20mm is increased so that screw can actually fit into it. And it is necessary to change all the components which are associated with the LM guide.
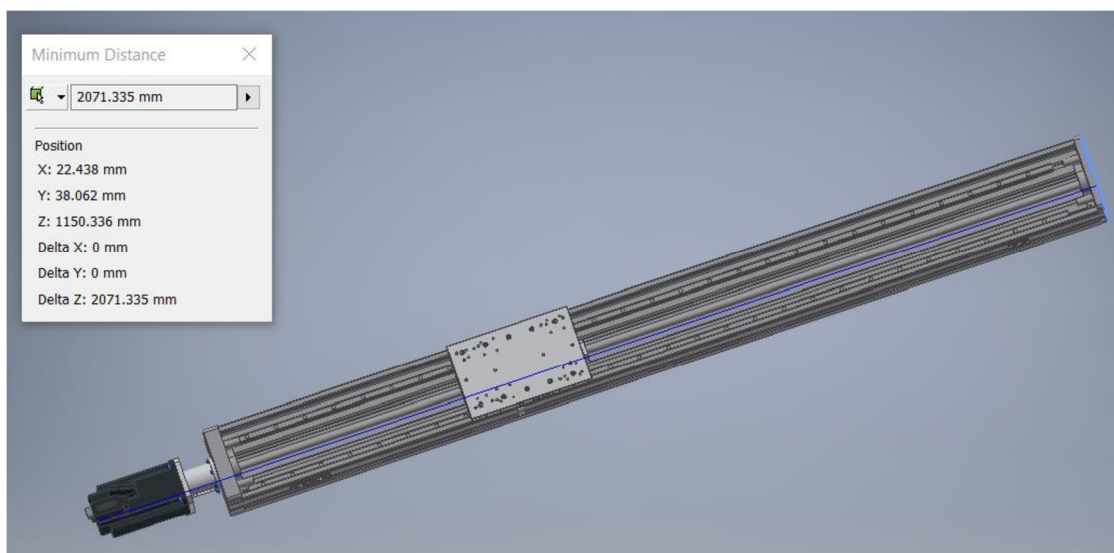
Figure 34:Linear actuator for X-axis

The figure above is the design of Linear Actuator for X-axis. I have taken BSU160 linear axis from HIWIN[40] which is the same as the existing one. The changes which are done from the existing one are the diameter and pitch. What happens to the acceleration if we increase the diameter and the pitch?

	PARAMETER	RESULT
Diameter increases	Feed rate	Increases
Pitch increases	Feed rate	Increases

Table 11: Effect of pitch and diameter to feed rate

21.2. CHANGES TO BE DONE IN Y-AXIS LINEAR ACTUATOR

From the calculation seen above, for us to achieve the required parameter, it is enough to concentrate on increasing the pitch unlike in X-axis linear actuator to achieve the required parameter. As seen above in the calculation, the diameter of the screw remains the same for the existing and the new one but it's just the pitch of the ball which is being increased. The feed rate is increased from 3.2m/min to 6.4m/min.
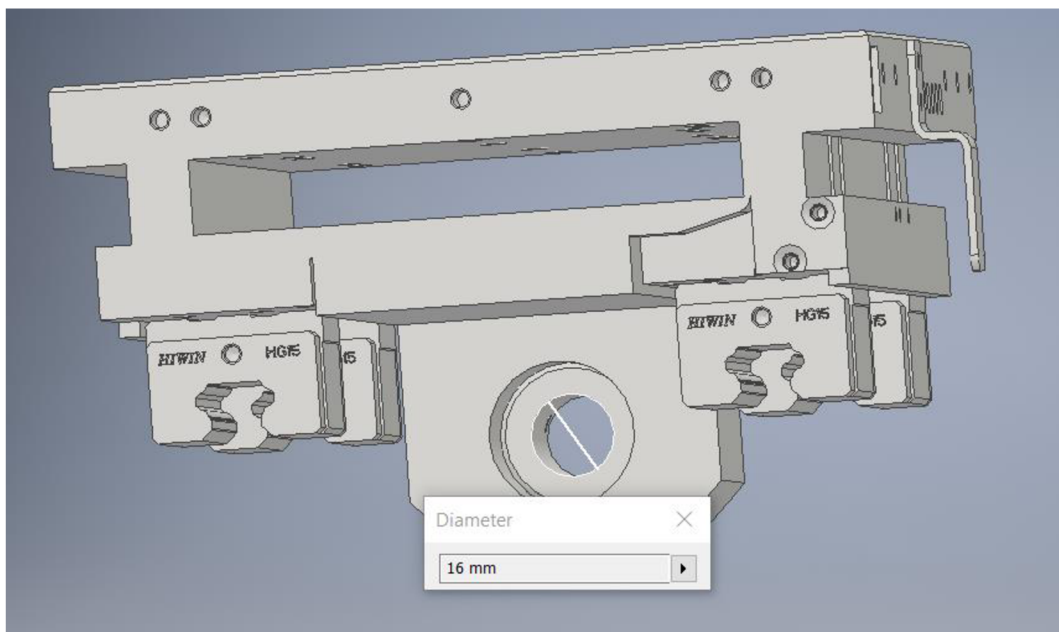
Figure 35: Ball screw diameter Y-axis actuator

As seen in the Figure 35, the diameter of the screw still remains the same but it is necessary to change the LM guide because of increases in the pitch of the screw. So, the ball diameter changes.
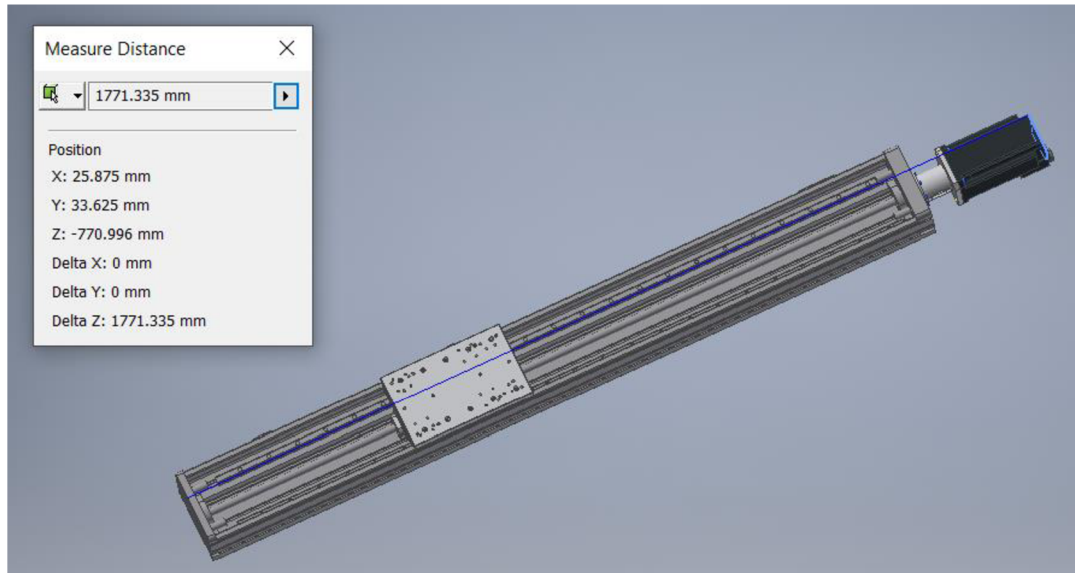
Figure 36: Y-axis Linear actuator

The design of the Linear Actuator for the X-axis may be seen in the diagram above. I used the existing BSU160 linear axis from HIWIN[37]. The pitch has been altered from the original. When the pitch is increased, what happens to the feed rate?

	PARAMETER	RESULT
Pitch increases	Feed rate	Increases

Table 12: Effect of pitch and diameter to feed rate

22. OTHER PARAMETERS

The other parameters which have to considered are

- Shaft design
- Bearing
- Retainer ring
- Keyway design
- Sealing
- Coupling
- LM guide

Let us take a look at these following parameters in the following passages.

22.1. SHAFT DESIGN

With increase in diameter of the ball screw, the diameter of the shaft which connects the screw and the coupling also increases. So, it is necessary to change the coupling and the keyway.
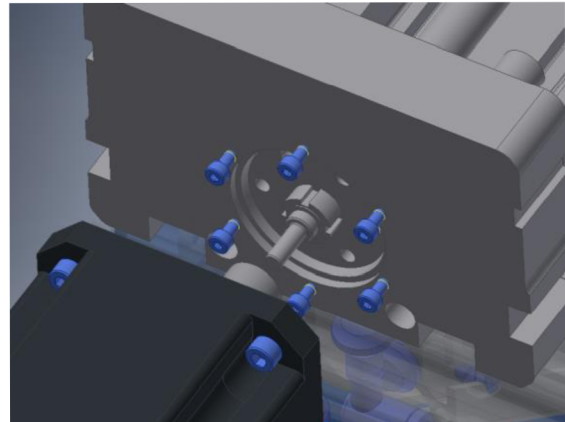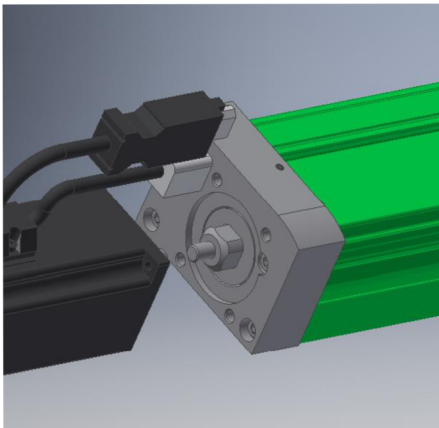
Figure 37: Shaft which connects coupling and Linear actuator

CALCULATION OF SHAFT DIAMETER

It is important to determine the shaft diameter from the torque based on the greatest torque that can be passed via the shaft or the greatest amount of twist in the shaft when a shaft is transmitting power from driver equipment to driven equipment. Otherwise, the shaft may not meet the equipment's functioning requirements.[42]

$$\textbf{Shear stress}[42], T = \tau . \frac{\pi}{16} . d^3 \tag{13}$$

So, we need the following data,

- Maximum torque that may be transmitted through the shaft (We can calculate torque from the Power and the speed also)
- The material's torsional shear stress

22.2. BEARING

Bearing is used to,

- to decrease friction between spinning parts.
- to carry weight in both axial and radial directions depending on the application of usage.
- Smooth rotation of shafts.
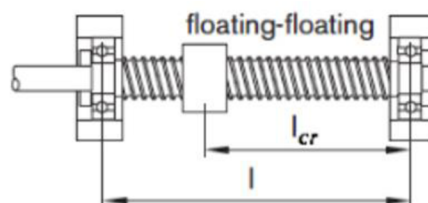
Figure 38: Floating-floating end Fixity Condition[43]

Since we are using floating-floating end fixity condition, it is necessary to use bearings on either ends and also since the diameter of the screw increases, it is necessary to increase the diameter of the bearings. With change in bearing, bearing housing should also be changed.

22.3. RETAINING RING

- Retaining ring are used to secure bearing in place.
- The diameter of the retaining ring changes with change in internal and external diameter of the bearings.
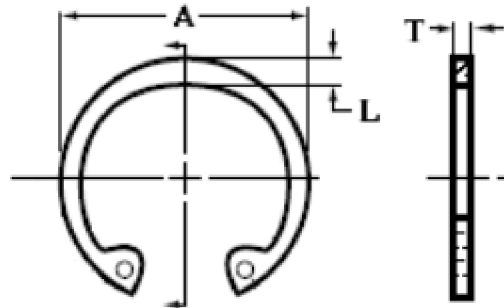
Figure 39: Retaining Ring[44]

22.4. KEYWAY DESIGN[45]

To prohibit relative movement between a power transmitting shaft and a connected component, keys and keyways lock the hub and shaft.

Shaft		Key	Key way					
Nominal Diameter		Size	Width (b)					
				Free				
d			Nom	Shaft (H9)		Hub (D10)		
Over	Incl	b x h		Min	Max	Min	Max	
6	8	2x2	2	0	+0,025	+0,02	+0,06	
8	10	3x3	3	0	+0,025	+0,02	+0,06	
10	12	4x4	4	0	+0,03	+0,030	+0,078	
12	17	5x5	5	0	+0,03	+0,030	+0,078	
17	22	6x6	6	0	+0,03	+0,030	+0,078	
22	30	8x7	8	0	+0,036	+0,040	+0,098	
30	38	10x8	10	0	+0,036	+0,040	+0,098	

Table 13: Standard dimension for keyway design[45]

So, with increase in diameter of the shaft, the keyway size also increases. So, it is necessary to increase the size of the keyway since we are increasing the diameter from 16mm to 20mm.

22.5. SEALINGS

Oil seals protect shafts and bearings against dirt and foreign object entry as well as oil or grease outflow. An oil seal is made up of an exterior circular metal portion and an inside flexible element that accomplishes the actual sealing and is chemically linked to the metal portion. The sealing component is constructed of rubber, which can be synthetic or natural depending on the situation.[46]

Figure 40: Sealing for protection[46]

So, with increase in diameter of the shaft and bearings, sealing diameter also increases.

22.6. COUPLING

A shaft coupling is a mechanical component that transmits power by connecting the driving shaft and driven shaft of a motor, for example. Shaft couplings provide mechanical flexibility, allowing for shaft misalignment to be tolerated. As a result of this coupling flexibility, uneven bearing wear, equipment vibration, and other mechanical issues caused by misalignment can be reduced.[47]

All motion units employed bellows coupling TOOLFEX type M size 20 from a German business KTR Kupplungstechnik GmbH to link the shaft of the linear unit to the shaft of the servomotor. The coupling is backlash-free, requires no maintenance, is very torsional robust, and has a low moment of inertia.
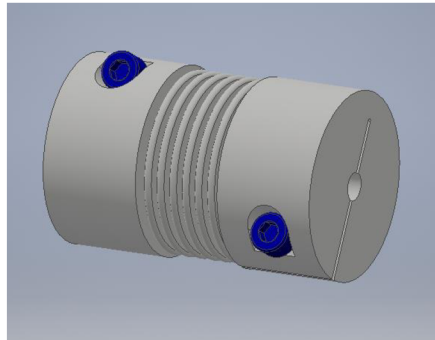
Figure 41: TOOLFLEX coupling used in the design

Also, this picture explains of how the tool flex coupling is coupled with the shaft.
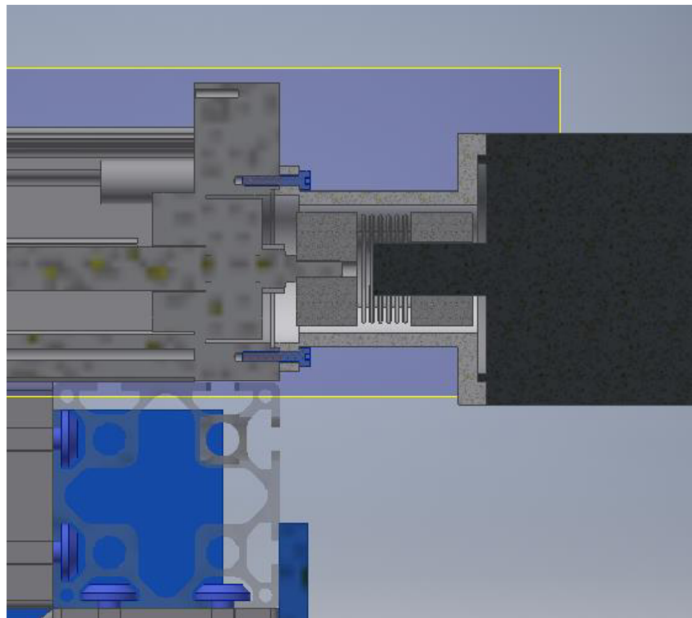
Figure 42: Shaft and coupling assembly

This clearly explains about the coupling which has to be replaced if the shaft diameter changes.

22.7. SHAFT-BEARING-RETAINING RING-SEALING ASSEMBLY
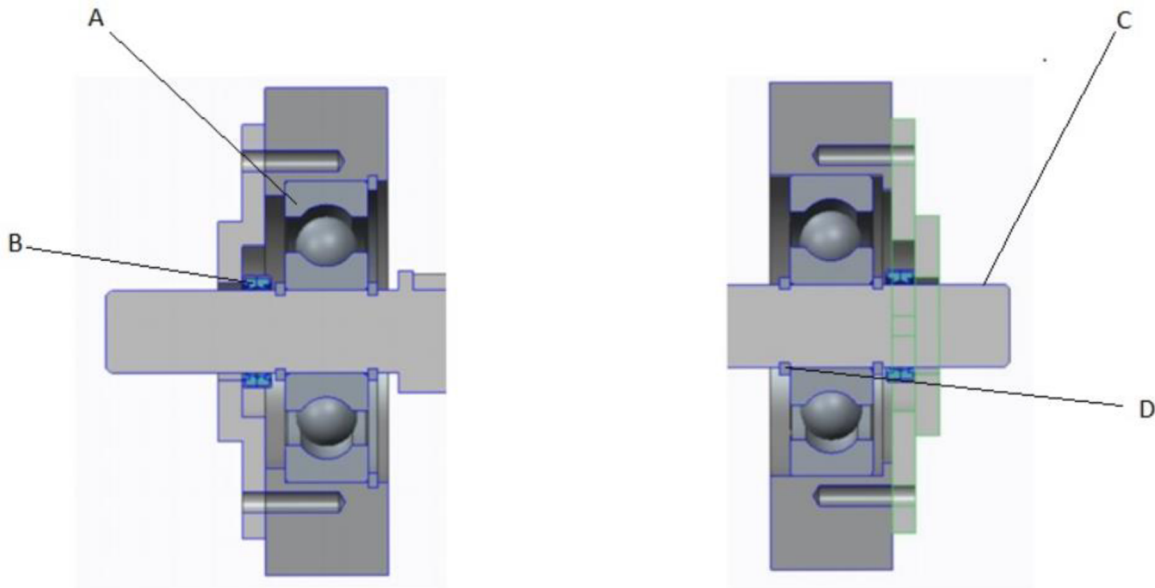
Figure 43: Shaft, Bearing, retaining ring and Sealing assembly

Whereas,

- A- Bearing
- B- Oil sealings
- C- shaft
- D- Retaining ring

This assembly clearly explains us the assembly of Shaft, bearing, oil sealing and retaining rings. Bearings on the shaft are positioned in such a way that they compensate for the warmth that occurs during operation when they expand. As a result, parts of the bearing's edges must be left unprotected, as indicated in the diagram above. The bearing on the left side is securely fastened.

This whole assembly has to be changed if the diameter of the ball screw increases.

22.8. LM GUIDE

The LM Guide (Linear Motion Guide), is the first in the world to incorporate a component with a linear rolling motion into practical use. It allows for the creation of high-precision, high-rigidity, energy-efficient, high-speed machines with long service life.
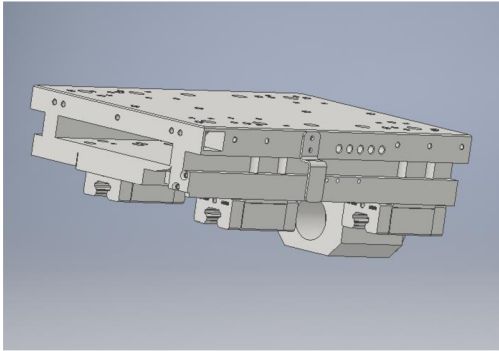
Figure 44: Linear motion Guide   **Figure 45: Part Name - LM Guide**[48]
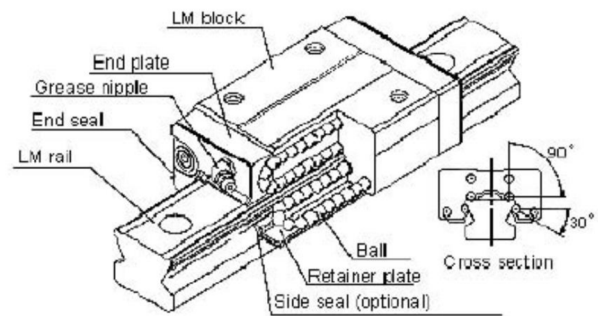
So, with increase in pitch and diameter, it is necessary to change the LM guide.

22.9. STATUS ON THE BALL SCREW LINEAR ACTUATOR

While on increasing the feed rate, it is necessary to increase the diameter and pitch of the ball screw as seen above. While on doing that, there is a lot of design modifications to be done to the linear actuator to actually make it function. Also, it's a lot of time to actually do the purchasing and it's not really sure if it is possible to get the specific part alone. It is also a lot of money if you get the specific part alone.

So, it better to replace the whole of linear actuator with the new one.

23. ISSUES OF INCREASING ROTATION SPEEDS[41]

Increasing the pace of a ball screw is related to the following high-level difficulties.

- Speed limitations will be based on dm and n values where dm is ball diameter and n are rotational speed. Harm to the ball recirculation circuit elements, such as tangs of return tubes, can become non-negligible as the orbital speed (dm and n value) of the steel ball increases.
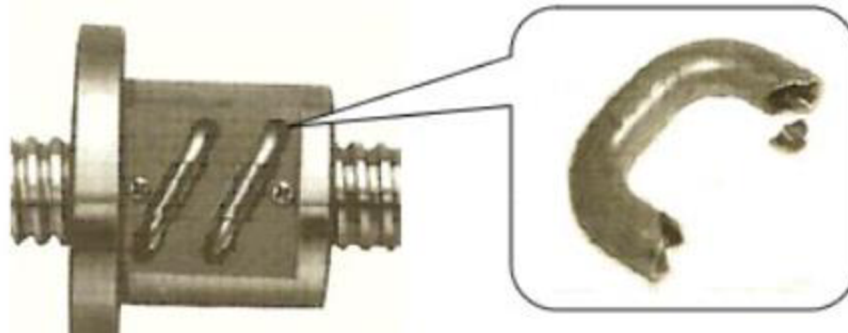
Figure 46: Return tube breakage [41]

- A ball screw's critical speed is the speed at which the screw begins to experience bending vibrations.

$$n_c = k \left(\frac{d_n}{(L_{CR}^2)} \right) . 10^7 \text{ min}^{-1} \tag{14}$$

- As the ball screw is rotated at high speeds, the normal frequency of the long slender shaft suspended at both ends reaches a critical speed, causing a resonance vibration phenomenon.

- Heat rise causes thermal deformation to increase. Since the friction torque between the steel balls and the shaft increases as the speed increases, the temperature of the ball screw will rise. Heat expansion occurs as a result of the temperature increase, and precision suffers as a result.

- Increased vibrations. Internal discontinuities in ball screw nuts trigger dynamic recirculation routes (not smooth). The related sounds and noises would increase as the ball speed increases.

- Owing to high-speed motion and high acceleration/deceleration, the load (inertia, etc.) increases. The loads on the ball screw rise as the ball screw imparts high speed and high acceleration motion to objects.

24. VARIANT 2: LINEAR MOTOR

24.1. INTRODUCTION

A Linear Induction Motor (LIM) is a type of rotary induction motor that produces a linear translational motion rather than a circular motion. The stator is axially chopped and flattened. The stator and rotor in this sort of motor are referred to as main and secondary, respectively. Isn't it true that electric motors spin in circles? Certainly not. A linear motor is a motor that provides straight-line motion rather than rotating motion. It was invented over a century ago. Inventors and engineers have produced many different types of linear motors through the years, suited for a wide range of applications. Because these odd motors have begun to make their way into machine tools in recent years, you've definitely heard machine makers boasting devices with "linear" in the name.[13]
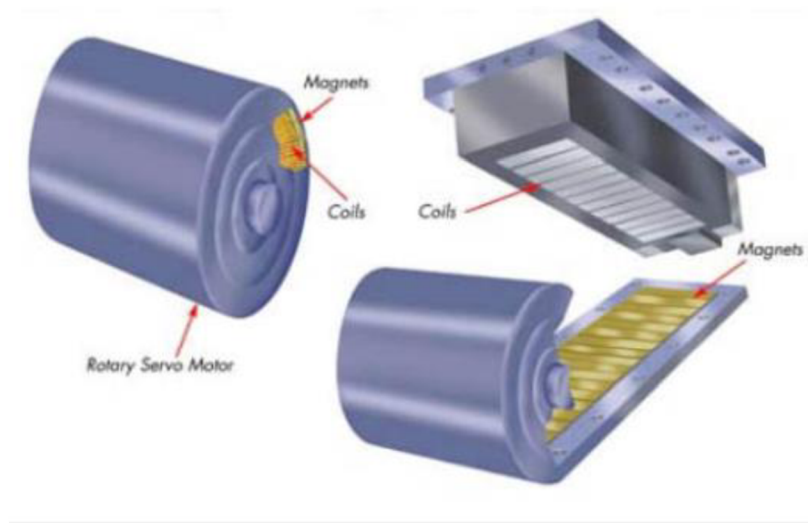
Figure 47:Unrolling a rotary motor to show how it relates to Linear motor[13]

24.2. HIWIN LINEAR MOTORS

HIWIN linear motors are a space-saving alternative for linear drive application. You have a high force field density and a flat design, which makes you stand out. These drives can function with high dynamic loads due to their low weights. The stator's permanent magnets are optimized, which ensures maximum synchronization or more drives.[49]

24.2.1. BASIC OVERVIEW OF LINEAR MOTORS IN HIWIN

DRIVING ELEMENT	MODEL	WEIGHT (kg)	MAX. SHEAR FORCE (N)	MAX. STROKE (mm)	ACCURACY (mm)
AXES with LINEAR MOTOR	LMU160L	60.00	5000	5050	±0.005
	LMU210	120.00	5000	3970	±0.005
	LMU250	200.00	5000	4070	±0.005

Table 14: HIWIN Linear motors[49]

These are the available models in the HIWIN and we will now have to choose the best model which will be suited for the purpose. And to get a better picture of what to choose out from the three, we will have to compare these parameters with the ball screw linear actuator to find the optimal one.
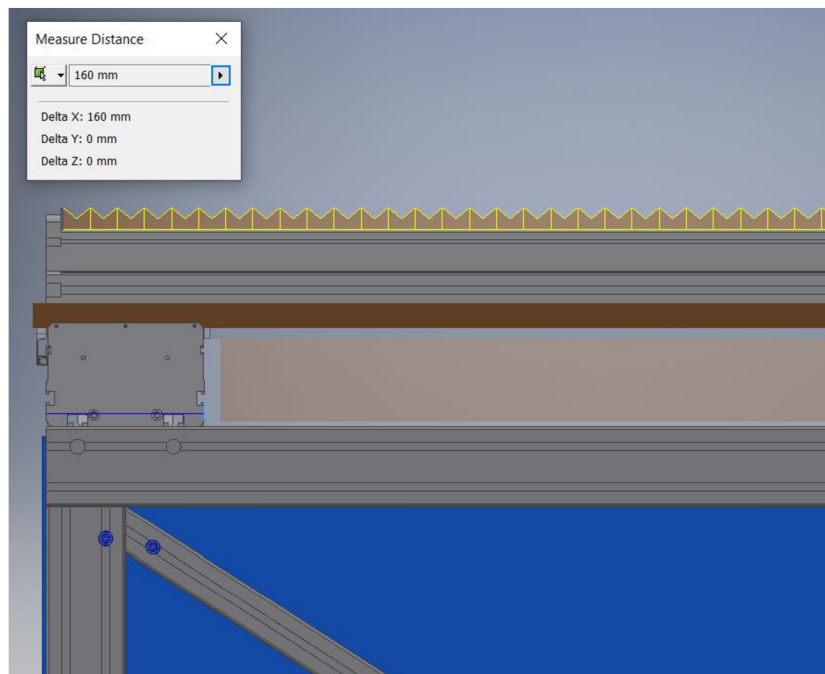
Figure 48:Ball screw linear actuator width

The main aim is that the frame or the base remains the same. And the above figure shows us that the ball screw linear actuator's width is 160mm. So, we will have to choose a linear motor which does not exceed 160mm so that the frame and the base doesn't have to be changed. And LMU160 has the same width of 160mm. But, that's not the only parameter which we got consider. So, let's compare and see which one is the best.

24.3. COMPARING THE PARAMETERS OF BALL SCREW LINEAR ACTUATOR AND LINEAR MOTOR

DRIVE TYPES PARAMETERS	BALL SCREW LINEAR ACTUATOR (BSU160)	LINEAR MOTOR (LMU160)
ACCURACY (mm)	±0.023 or 0.052	±0.005
MAX. ACCELERATION (m/s^2)	15	50
TYPICAL LOAD of the linear drive (kg)	60	60
Static load capacity of linear guide (N)	16970	16970
Dynamic load capacity of linear guide (N)	11380	11380
STROKE LENGTH (m)	1.7	5
MAX. VELOCITY (m/s)	0.67	16
Weight of the slider (kg)	5.5	10
Weight of static part (kg)	17	15
MOTOR USED	Drive-stepper or servo motor (mostly gearbox)	Integrated motor series LMSA

Table 15: Comparison of two variants[49]

From the above comparison between ball screw linear actuator and linear motor, it will give us an idea or better understanding of the design and what linear motor to move forward with. Also, we can evaluate or understand what linear motor can be assembled on to the existing system without doing any changes to the base. Looking at the first parameter, which is accuracy, linear motor has got better accuracy compared with ball screw actuator. Also, the load in which the frame or base which is going to withstand is the same. The static load capacity and dynamic load capacities of two actuators are the same.

24.4. LMU160 Actuator

LMU160 is produced by HIWIN and is a linear motor with an accuracy of $\pm 0.005 mm$. It has a maximum length up to 5m. It is a non-contact actuator so there won't be any mechanical wear to the components. Since it's a non-contact linear actuator, it won't need any constant maintenance check. The maximum speed of this actuator is up to 16m/s and the maximum acceleration is up to 50m/s^2. The maximum stroke length is up-to 5 meters. The motor used here is integrated motor series LMSA. The maximum weight of the slide is 10 kg and the weight of the static part is 15 kgs.

Figure 49: LMU160 actuator[32]

24.5. LINEAR UNITS (LINEAR MOTOR)
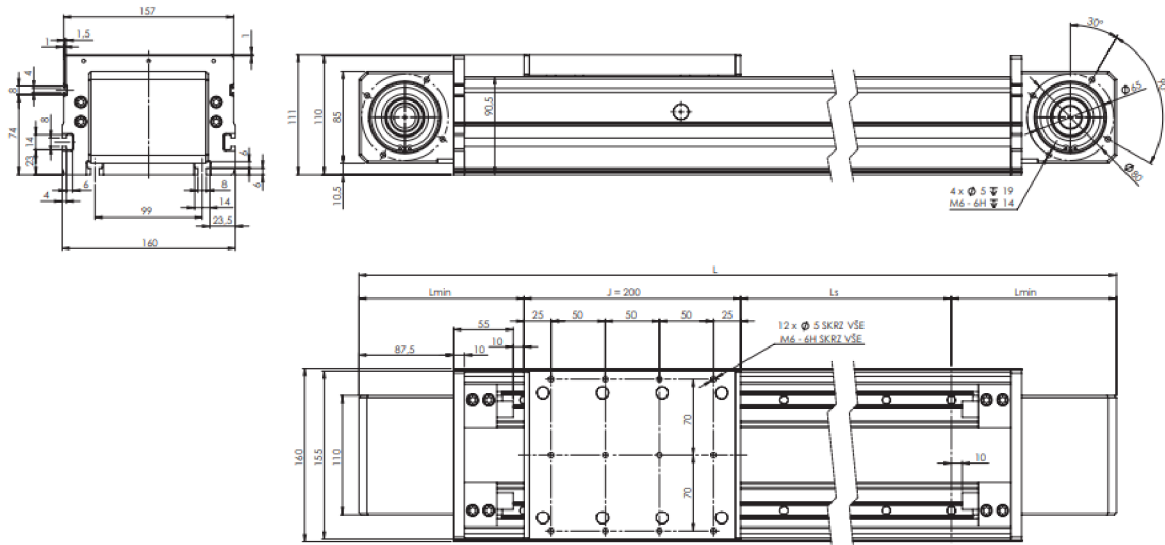
Figure 50: Design configuration of LMU160[49]

Figure 50clearly explains about size and dimension of the LMU160. As you can see, the width of the actuator is 160 mm which clearly can assemble and fit on to the frame. There are three sliders based on their lengths and the LMU are even categorized more based on the type of sliders. The slider is nothing but the LM guide.
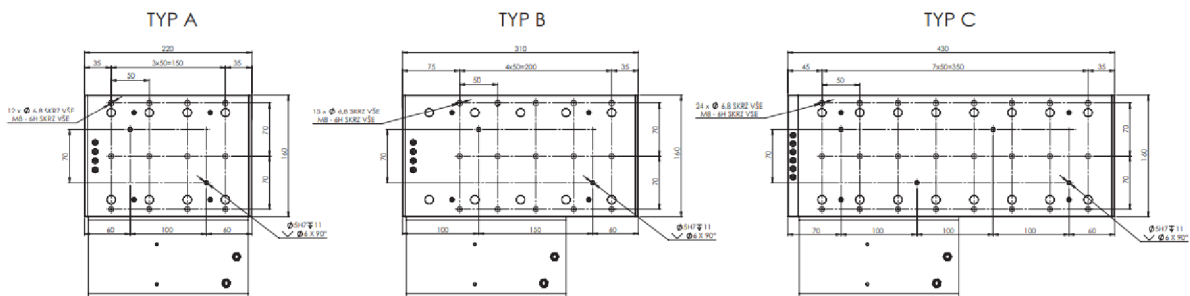
Figure 51: Types of Sliders[49]

These are the three types of sliders based on the length and now we will have to choose which kind of slider we want for our purpose. The length of the slider type A is 220mm and the length of the slider type B and C are 310mm and 430mm respectively. And since we are going to mount the Y-axis linear motor on the Slider, it is enough to choose between Type

and Type B. For my purpose, I am going with Type B slider since we will have to mount and assembly using a counter bracket.

Part number	Motor	Type of slider	Continous force Fc [N]	Peak force Fp [N]	Max. speed Vmax [m/s]	Max. acceleration Amax [m/s2]	Weight of slider [kg]	Weight of static part [kg/m]
LMU160L-01	LMSA11C	A	103	379	8	50	6	15
LMU160L-02	LMSA11LC	A	103	379	16	50	6	15
LMU160L-03	LMSA12C	B	205	759	8	50	8	15
LMU160L-04	LMSA12LC	B	205	759	16	50	8	15
LMU160L-05	LMSA13C	C	308	1138	8	50	10	15
LMU160L-06	LMSA13LC	C	308	1138	16	50	10	15

Table 16: Types of LMU160 based on the types of Slider[32]

Based on the design requirement, I am going with LMSA12LC.

24.6. DESIGN ISSUES

- Air gap length
- End effect
- Edge effect
- Effect of unrolling

When using a traction system, the airgap can be as large as 5 cm for LIM. For large airgaps, the magnetic reluctance is substantially higher, and the magnetizing current is likewise larger. The operational p.f. is further reduced by a substantial leakage flux. The fact that LIM has ends distinguishes it from typical rotary motors.

This implies that the traveling magnetic fields are unable to link together, resulting in end consequences. The magnetic pattern seems to be undisturbed when the rotary machine is divided and unrolled into the corresponding linear circuit. This is only true for a brief period of time. The condition alters after a quarter cycle, which is known as the impact of unrolling.

The goodness factor, G, is another important design aspect. The major source of current for an induction motor is drawn from the main circuit, which is then transferred to the secondary circuit by induction across the airgap. The mechanical energy to drive the load is the difference between the power delivered over the airgap and the rotor losses.[50]

25. DRAWING DOCUMENTATION

In the drawings attached after reference, I have attached the technical drawings of X-axis and Y-axis ball screw linear actuator. Since I could not get the CAD models from HIWIN, I have explained about the drawing changes to be done on the ball screw actuator. The screw diameter of the X-axis linear actuator increases from 16mm to 20 mm where in the width and the stroke length remains the same. So, it does not affect the frame construction. And in the other drawing explains about the changes to be done in the Y-axis linear actuator. The screw diameter remains the same but only the pitch diameter varies.

PARTS LIST

ITEM NO.	QUANTITY	NAME
1	1	LINEAR DRIVE
2	1	CARRIAGE
3	1	COUPLING
4	1	MOTOR
5	6	$M4 \times 20$
6	4	$M6 \times 20$

Table 17: Parts list

26. CONCLUSION

The goal of the diploma thesis was to design and innovate the motion axes of the laser machine, with the possibility of putting them into practice. As a result, examples of commercially produced comparable machines are presented at the beginning of this work (save for a brief introduction to the topic of laser and laser cutting). In addition to laser cutting machines, certain modeling milling machines have been studied and compared, since the prospective fitting of a prototype milling machine is anticipated to have a rapid spindle. After comparing the machines and their drive types, it is now necessary to choose the drive types which possess more advantages while implementing on laser machines. So, on comparison, the two variants which is been used are ball screw linear actuator and linear motor.

After figuring out the drive types, it is important to work on the drive type design and calculation part. Therefore, the parameters (diameter, length, pitch and co-efficient of end support bearings) which is going to influence the design of ball screw linear actuator are analyzed. These parameters play an important role during the calculation part and the standard dimension for the ball screw is also detailly explained.

Control calculations of drives were done for the machine's X and Y axes. In the X-axis, the feed rate is increased from 2.2 m/min to 5.8 m/min by increasing the diameter of the screw from 16mm to 20 mm and also increasing the pitch from 5mm to 10mm and in the Y-axis, the feed rate is increased from 3.2m/min to 6.4m/min by increasing the pitch from 5mm to 10mm. It is now necessary to determine the design changes to be done while on increasing the pitch and the diameter. Also, it is necessary to decide if it will be the best to just do the design changes or change the whole of linear actuator.

In the next chapter, I described about the design changes which has to be done on increasing the diameter and the pitch. Other than changing the diameter and the pitch, there are really more changes which has to be done to get the design done. So, considering that, it is better to change to whole of linear actuator.

Talking about the next variant which is linear motor has got many advantages and it is one of the latest technologies which is being adapted by many industries. Since, the base or frame is going to remain the same, it is necessary to choose a linear motor which is of same

width as that of the previous one. That is the first and foremost parameter to be considered. Based on width, LMU160 is picked.

Comparing these two variants, linear motor has got many advantages over ball screw linear actuator. Unlike ball screw actuator, it's a non-contact drive type. So, there is not going to be any mechanical wear and there is no need of periodic maintenance like in ball screw actuator. The accuracy of linear motor is higher than ball screw linear drive.

The design of the linear motor actuator as shown in this paper is not completely complete. The assignment's goals for the task were all satisfied. Different types of linear drives can also be used. Rack and pinion linear drive, for example, has been frequently employed in laser cutting machines. All of this might be the subject of future diploma or bachelor's theses.

REFERENCE

[1]   High-power direct-diode lasers for cutting and welding. *www.industrial-lasers.com* [online]. undated [vid. 2021-05-25]. Available https://www.industrial-lasers.com/articles/print/volume-29/issue-3/features/high-power-direct-diode-lasers-for-cutting-and-welding.html

[2]   KELLY, H. Linear drives. *Industrial robot*. 1993, **20**(6), 8–11. ISSN 0143-991X.

[3]   *Linear Actuator: What Is It? How Does It Work? Types Of* [online]. [vid. 2021-04-05]. Available https://www.iqsdirectory.com/articles/actuator/linear-actuator.html

[4]   *The 4 Types of Linear Actuators* [online]. [vid. 2021-04-05]. Available https://www.deltron.com/Linear-Actuators.html

[5]   *What is a Hydraulic Actuator ? | Instrumentation Tools* [online]. [vid. 2021-04-05]. Available z: https://instrumentationtools.com/what-is-a-hydraulic-actuator/

[6]   *How Pneumatic Actuators Work | Pneumatic Actuator Uses & Applications* [online]. [vid. 2021-04-05]. Available https://www.semcor.net/blog/advantages-of-pneumatic-actuators/

[7]   *Schematic diagram of double acting pneumatic actuator system. | Download Scientific Diagram* [online]. [vid. 2021-04-05]. Available https://www.researchgate.net/figure/Schematic-diagram-of-double-acting-pneumatic-actuator-system_fig1_234778498

[8]   *What are Single Acting & Double Acting Hydraulic Cylinders | by VComp Inc | Medium* [online]. [vid. 2021-04-06]. Available https://medium.com/@vcompmississaug/what-are-single-acting-double-acting-hydraulic-cylinders-817d6e6f30a8

[9]   *Rack and pinion - Wikipedia* [online]. [vid. 2021-04-22]. Available https://en.wikipedia.org/wiki/Rack_and_pinion

[10]   *Profiled rail + rack & pinion = integrated solution* [online]. [vid. 2021-04-22]. Available https://www.linearmotiontips.com/profiled-rail-rack-pinion-integrated-solution/

[11]   *Introduction to Piezoelectric Actuators • Smashing Robotics* [online]. [vid. 2021-04-06]. Available https://www.smashingrobotics.com/introduction-to-piezoelectric-actuators/

[12]   LU, Qian, Xifu CHEN a Weiqing HUANG. A novel rhombic piezoelectric actuator applied in precision positioning stage. *Journal of Applied Science and Engineering* [online]. 2020, **23**(3), 405–411 [vid. 2021-04-06]. ISSN 15606686. Available doi:10.6180/jase.202009_23(3).0004

[13]   *How it Works – The Line on Linear (Motors) | Today's Machining World* [online]. [vid. 2021-05-25]. Available https://todaysmachiningworld.com/magazine/the-line-on-linear-how-linear-motor-works/

[14]   *China Tmz Magnetic Linear Servo Motor with Excellent Stability and Accuracy for Laser Cutting Machine - China Linear Actuator, Iron-Core Linear Motor* [online].

[vid. 2021-05-25]. Available https://tiayoumodule.en.made-in-
china.com/product/tZVENQeYhncw/China-Tmz-Magnetic-Linear-Servo-Motor-with-
Excellent-Stability-and-Accuracy-for-Laser-Cutting-Machine.html

[15]   *4 Driving Methods of Laser Cutting Machine | MachineMfg* [online]. [vid. 2021-05-
25]. Available: https://www.machinemfg.com/laser-cutting-machine-driving-
methods/

[16]   *The Fundamentals of Ball Screws | Machine Design* [online]. [vid. 2021-02-20].
Available https://www.machinedesign.com/mechanical-motion-systems/linear-
motion/article/21834347/the-fundamentals-of-ball-screws

[17]   *- Learn Before You Buy!* [online]. [vid. 2021-02-21].
Available: http://www.motioncontrolguide.com/learn/guides/ball-screw-guide/

[18]   TAUCHMAN, Jan. *Technická univerzita v Liberci Fakulta strojní KONSTRUKCE
PROTOTYPU CNC STROJE PRO LASEROVÉ ŘEZÁNÍ PLECHŮ*. undated.

[19]   *FlatCom® M series...with servo motor drive | isel Germany AG* [online]. [vid. 2021-05-
06]. Available https://www.isel.com/en/flatcom-series-m.html

[20]   *CNC milling system - GPV / GPY - imes-icore* [online]. [vid. 2021-05-06].
Available: https://www.imes-icore.de/esp/fresadora-serie-gpv-html.html

[21]   *TruLaser 1030 fiber | TRUMPF* [online]. [vid. 2021-05-07].
Available https://www.trumpf.com/en_INT/products/machines-systems/2d-laser-
cutting-machines/trulaser-1030-fiber/

[22]   CLASSIC, Trumpf. TruLaser 1030 fiber. 2010, 1–14.

[23]   *Farley LaserLab Profile Plus CO2 Laser - AG Holding* [online]. [vid. 2021-05-07].
Available https://www.agholding.com.au/Services/bystronic-byspeed-3015-with-
byloader-2/

[24]   *Wood - Cutting Machine M-1600* [online]. [vid. 2021-05-07].
Available https://www.eurolaser.com/cz/laserove-systemy/laser-systems-for-
wood/m-1600-wood/

[25]   *Cutting Machine, M-1600, EUROLASER GMBH, Germany* [online]. [vid. 2021-05-07].
Available https://www.europages.co.uk/Cutting-Machine/EUROLASER-GMBH/cpid-
5328604.html

[26]   *Modular automation for every manufacturing need* [online]. [vid. 2021-05-07].
Available https://www.salvagnini.com/en/product/fiber-laser/l3/automation

[27]   FROM百度文库. 済無No Title No Title. *Journal of Chemical Information and
Modeling*. 2013, **53**(9), 1689–1699. ISSN 1098-6596.

[28]   *Vanad - Vanad KOMPAKT Laser* [online]. [vid. 2021-05-20].
Available: https://vanad.cz/en/cutting-machines/vanad-machinery/vanad-kompakt-
laser

[29] *3D fiber laser machine Rapido | Prima Power* [online]. [vid. 2021-05-20]. Available https://www.primapower.com/us/rapido-3d-laser-machine/#1448982719858-0eaae0f8-b51dfc72-a00fae4f-fbacb154-8605

[30] *Laser ENGLISH.pdf*

[31] *Lineární osa BSU160 | hiwin.cz* [online]. [vid. 2021-05-20]. Available: https://www.hiwin.cz/en/products/linear-axis/ball-screw-drive-axis/linear-axis-bsu/306_linearni-osa-bsu160

[32] *Linear axis LMU160L | hiwin.cz* [online]. [vid. 2021-05-20]. Available https://www.hiwin.cz/en/products/linear-axis/linear-motor-axis/linear-axis-lmu/307_linear-axis-lmu160l

[33] *Ball Screws: The Basics - Making Motion Work* [online]. [vid. 2021-02-20]. Available http://www.makingmotionwork.com/ball-screws-the-basics/

[34] Effects of Change in Parameter on Ball Screw Characteristics. undated, 5204.

[35] *What is the difference between screw pitch and lead?* [online]. [vid. 2021-02-21]. Available: https://www.thomsonlinear.com/en/support/tips/difference-between-screw-pitch-and-lead

[36] LEARNING, Machine a R COOKBOOK. bakalarska_prace_2018_Stepan_Lanik.pdf. undated.

[37] *LAO - lasers and optics* [online]. [vid. 2021-02-20]. Available http://www.lao.cz/

[38] *TAEevo Fail-safe operation*. undated.

[39] *smallest diameter ball screw | Precision Ball Screw Technology* [online]. [vid. 2021-02-15]. Available: https://ballscrew-tech.com/tag/smallest-diameter-ball-screw/

[40] *Lineární osa BSU160 | hiwin.cz* [online]. [vid. 2021-02-25]. Available https://www.hiwin.cz/en/products/linear-axis/ball-screw-drive-axis/linear-axis-bsu/306_linearni-osa-bsu160

[41] *Mastering Ball Screws 4- Increase in Speed | MISUMI Blog* [online]. [vid. 2021-04-04]. Available https://blog.misumiusa.com/mastering-ball-screws-pt-4-increase-in-ball-screw-speeds/

[42] *How to calculate the shaft diameter from the torque? - ExtruDesign* [online]. [vid. 2021-05-18]. Available https://extrudesign.com/calculate-shaft-diameter-from-torque/

[43] *What is ball screw whip and why does it happen?* [online]. [vid. 2021-05-18]. Available https://www.linearmotiontips.com/what-is-ball-screw-whip-and-why-does-it-happen/

[44] *Retaining Rings Types and Applications - Engineers Edge* [online]. [vid. 2021-05-18]. Available https://www.engineersedge.com/hardware/retaining-rings-about.htm

[45] *Keys & keyways specification | Engineering Product Design* [online]. [vid. 2021-05-19]. Available https://engineeringproductdesign.com/knowledge-base/keys-keyways-

specification/

[46] *Oil Seal - an overview | ScienceDirect Topics* [online]. [vid. 2021-05-19].
      Available https://www.sciencedirect.com/topics/engineering/oil-seal

[47] *About Shaft Couplings | NBK | The Motion Control Components* [online]. [vid. 2021-
      05-19].
      Available https://www.nbk1560.com/en/resources/coupling/article/powertransmissi
      on-about/?SelectedLanguage=en

[48] *Schematic of the LM (Linear Motion) guide. | Download Scientific Diagram* [online].
      [vid. 2021-05-19]. Available https://www.researchgate.net/figure/Schematic-of-the-
      LM-Linear-Motion-guide_fig1_226865448

[49] Polohovací systémy. 2017.

[50] SAHA, Debasree, Priyanath DAS a Sumana CHOWDHURI. Design trends of linear
      induction motor (LIM) and design issues of a single sided LIM. In: *International
      Conference on Control, Instrumentation, Energy and Communication, CIEC 2014*
      [online]. B.m.: Institute of Electrical and Electronics Engineers Inc., 2014, s. 431–435.
      ISBN 9781479920440. Dostupné z: doi:10.1109/CIEC.2014.6959125

X-AXIS LINEAR ACTUATOR

2090

160.00

Width

the diameter of the screw is increased
from 16mm to 20mm

∅20

SECTION C-C
SCALE 1 / 4

166

PARTS LIST			
ITEM	QTY	PART NUMBER	DESCRIPTION
1	1	linear_drive_1500	BALL SCREW
2	1	Carriage	
3	1	coupling	
4	1	Motor	
5	6	CSN021143M4X20	
6	4	CSN021143M6X16	

DRAWN: RAM KUMAR RAMESH 30-03-2021
CHECKED: PETR ZELENY
QA
MFG
APPROVED

Technical University Of Liberec

TITLE
LINEAR_ACTUATOR_X-AXIS

SIZE
A3

SCALE 1 / 4

DWG NO

REV

SHEET 1 OF 1

Y-AXIS LINEAR ACTUATOR

161

160.00

width

SECTION B-B
SCALE 1 / 4

Ø16

The diameter of the lead screw remains the same
since in the Y-axis, only the pitch diameter is changed.

160

1790

B

B

	PARTS LIST			
ITEM	QTY	PART NUMBER	DESCRIPTION	
1	1	Linear_drive_1200	BALL SCREW	
2	1	Carriage		
3	1	Coupling		
4	1	motor		
5	4	CSN021143M6X16		

DRAWN
RAM KUMAR RAMESH 29-03-2021
CHECKED
PETR ZELENY
QA
MFG
APPROVED

Technical University Of Liberec

TITLE
LINEAR_ACTUATOR_Y-AXIS

SIZE
B

DWG NO
linear_actuator_y-axis

REV

SCALE 1 / 4

SHEET 1 OF 1